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GREAT LAKES/ST. LAWRENCE SEAWAY REGIONAL TRANSPORTATION STUDY: --ETC(U)

AUG 81 A P FREE, R H SCHULZE, M R HORNE

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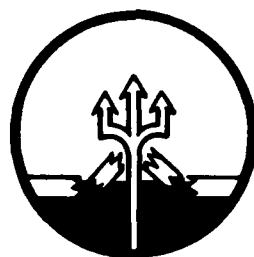
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Final Report No. 719C-5

GREAT LAKES/ST. LAWRENCE SEAWAY  
LOCK SYSTEM PERFORMANCE AND  
ALTERNATIVES FOR INCREASING CAPACITY

TASK 7 Report of Great Lakes/St. Lawrence  
Seaway Regional Transportation Studies

Prime Contract DACW 35-80-C0060

August 1981

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Submitted to

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increased capacity, methods of implementation , general effectiveness and cost. Six general categories of alternatives were studied and included reduced time by lockage, increased ship capacity, increased tonnage per lock, season extension, duplicate locks and other alternatives.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The report contains an overview of factors affecting the locking process and locking procedures for the different lock systems. The results of an analysis of locking time data for the lock systems is presented. Based on locking time data, engineering judgement, and interviews with lock operators eight lock time components were estimated for use in capacity studies. Alternatives for capacity expansion including physical improvements and changes in operating procedures were developed to meet the projected cargo demands without exceeding the capacities of the lock systems. Alternatives were evaluated regarding (con't)		

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## 1. SUMMARY

The objective of this task of the Great Lakes/St. Lawrence Seaway Regional Transportation Study was to determine lock system performance problems and develop and evaluate comprehensive non-structural and structural alternatives for increasing lock capacity. Capacity of a lock can be identified as the maximum amount of cargo tonnage which may be transported through it in a year. This objective was met by investigating the locking process and the available data on lockage time components; interviewing laker fleet operators, ocean fleet operators, and lock operators regarding existing lock problems; and developing a comprehensive list of capacity expansion alternatives with engineering estimates of the associated performance improvements and costs.

The investigation of the locking process and the available data on lockage time components revealed that there are broad differences in the concern over obtaining detailed lockage time data at the three lock systems. Data collected at the Soo Locks is quite limited, consisting only of an arrival time and a departure time. The situation is the same at the Canadian St. Lawrence River Locks where, again, only arrival and departure times are recorded. One additional time, the enter time, is recorded at the U.S. St. Lawrence River Locks. In sharp contrast to the situation at the Soo and St. Lawrence River Locks, extensive lockage time component data has been collected at the Welland in terms of nine times giving eight time increments. More importantly, this Welland data has been analyzed and condensed into summary form. The Welland lockage time data therefore serves as a basis upon which to build estimates of lockage time components for all three lock systems, with the resulting total lockage time being determined from the data collected at each lock system. Based upon an analysis of all available data, engineering judgement, and interviews with lock operators, eight lockage time components were estimated for each of the three lock systems with variations due to vessel class and direction of travel. These estimates are judged to be the best that can be obtained on the basis of the data available. Substantially higher confidence levels could only be realized after one or more years of extensive data collection at the Soo and St. Lawrence River Locks in a manner similar to that used at the Welland. The confidence level in the Welland data could be further improved only by additional years of data collection or the implementation of a totally automated data collection system. Such a system was under consideration for a period of time, but is no longer being actively considered.

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Lakes fleet operators would like to see larger locks, wider and deeper channels, and a second Poe-sized lock at the Soo. During peak operation, waiting lines of 20 to 30 vessels are reported at the Soo, and waiting periods as long as 5 days reported at the Welland. Lakes fleet operators feel that system capacity could be increased substantially by increasing the average load per transit. They feel the current system favors the smaller, less efficient carrier since, in general, the cost of locking ships is relatively independent of ship size. These operators also feel that the Coast Guard should go beyond just rendering assistance to vessels in distress during season extension to maintaining open channels with icebreaker operations.

Ocean fleet operators cite draft restrictions as the principal GL/SLS problem. The requirement for pilots is also cited as causing delays and unnecessary expense. International shippers report waiting lines of 15 to 20 ships at the Welland during peak periods.

Alternatives for increasing lock capacity were categorized in six groups according to capacity expansion objective. These are summarized as:

- Reduce time per lockage
- Increase ship capacity
- Increase tonnage per lockage
- Season extension
- Construct replicate locks
- Other.

In each category, one or more methods of accomplishing the general capacity expansion objective are outlined. A preliminary screening of possible capacity expansion alternatives is thus made and the remaining alternative methods are considered further. Each method is then analyzed and engineering estimates of the expected performance improvement and the cost of the improvement are made.

## 2. INTRODUCTION

The Great Lakes/St. Lawrence Seaway System (GL/SLS) provides a shipping link between the deep water of the Atlantic Ocean and ports 2400 miles inland on the American continent. This includes 1000 statute miles down the St. Lawrence River, 1350 miles over the Great Lakes, and 400 miles in connecting channels. In that distance there are sixteen sets of locks that lift ships from sea level to an elevation of 600 ft in Lake Superior. Figure 1 is a schematic cross-section of the GL/SLS system. Figure 2 shows the area covered by the system.

The capacity of any navigation system including the Great Lakes/St. Lawrence Seaway System is determined by the system's limiting or constraining element; the element which has the slowest processing time. In very general terms, the GL/SLS system can be thought of as a series of locks, connecting channels, and harbors. The complexity inherent in the three lock systems, the five connecting channels, and over forty harbors becomes even more significant when the numerous trade routes between the various harbors for inland traffic and for the ocean trade are also considered. Generally, for navigation systems equipped with locks, the traffic capacity defined either in terms of annual tonnage or annual vessel transits is constrained by the locks. Prior capacity studies of the GL/SLS system have indeed shown the locks to be the constraining element of this system. As the annual tonnage shipped on the GL/SLS navigation system continues to increase in the future, the demand for service at the locks will increase accordingly, and as the capacity limits of the system are approached vessels will begin to experience long waiting times and long vessel queues at the locks. The resulting inability of the system to effectively service its customers would obviously be reflected in a decrease in the popularity and use of the system, with an adverse impact on the economic growth of the entire nineteen state region served by the system. Forecasted cargos which exceed the existing capacity would be forced to seek alternate means of transport to satisfy regional requirements.

Any transportation system interested in serving its customers over the long term must plan to provide an expanded capacity when the need for such capacity is required by the system's users. For a simple system having one major constraining component, the removal of the constraint at that one point removes the system constraint. For a more complex system, such as the GL/SLS navigation system, the multiplicity of locks, connecting channels, and harbors presents a more challenging assignment to

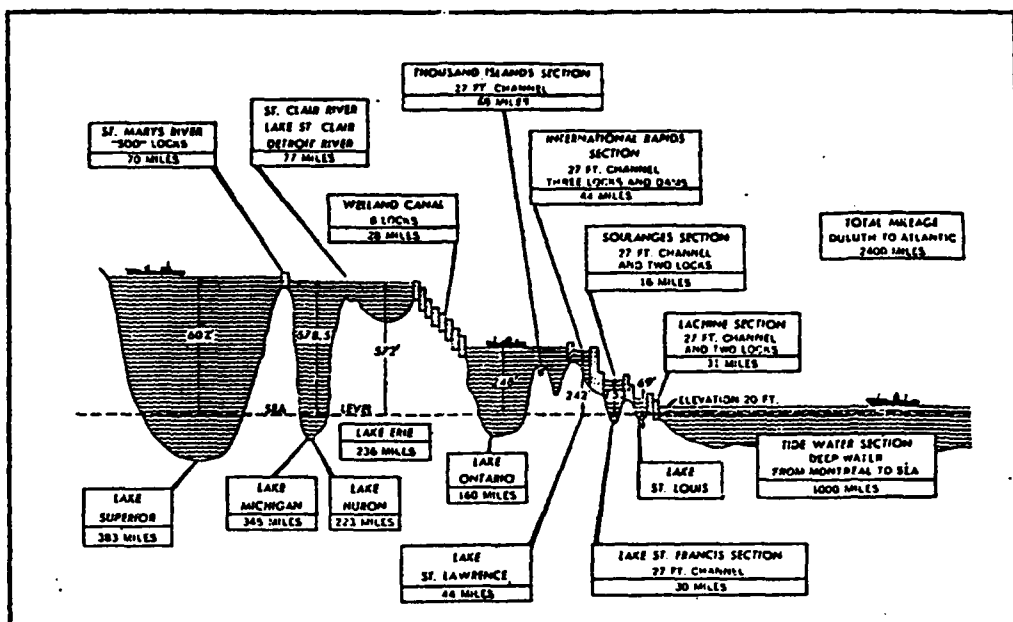


FIGURE 1 PROFILE OF GREAT LAKES-ST. LAWRENCE NAVIGATION SYSTEM

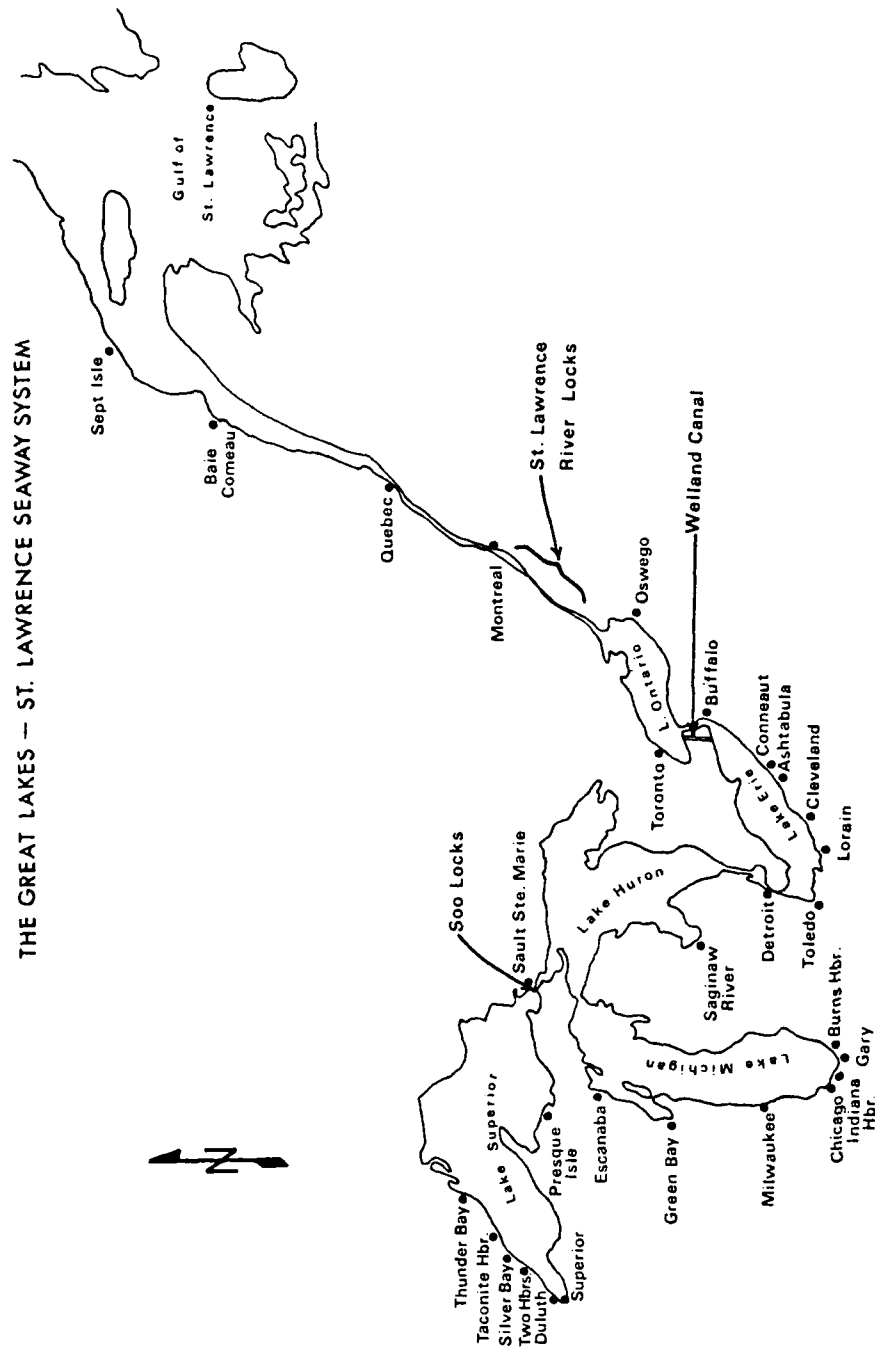


FIGURE 2. THE GREAT LAKES - ST. LAWRENCE SEAWAY SYSTEM

the planners addressing the removal of system capacity constraints over the long term. An analysis of the entire system is required to ensure that removal of a constraint at one feature or location does not simply result in movement of the constraint to another feature or location with relatively little, if any, improvement in overall system capacity.

With such considerations in mind, the North Central Division of the U.S. Army Corps of Engineers initiated a study entitled, "Great Lakes/St. Lawrence Seaway Regional Transportation Studies", having as its primary objective the development of a sound documented working tool for use in analyzing GL/SLS regional transportation improvement alternatives. This report documents the work of Task 7 of this program, the objective of which is to determine lock system performance problems, and develop and evaluate in a preliminary screening manner comprehensive non-structural and structural alternatives for increasing lock capacity through the year 2050. The approach specified in the scope of work for meeting this objective starts with an investigation of the locking process, followed by an analysis of available data on lock processing time components. Based on interviews with U.S. and Canadian ship owners and lock operators, problems currently being experienced at the locks were then identified. The final subtask consisted of the development of a comprehensive listing of non-structural and structural alternatives for increasing lock capacity. This work also included the development of estimates of performance improvement and cost for each of the alternatives.

The following sections of this report are organized in the same sequence as suggested by the scope of work in the ordering of the subtasks. The results of this work will apply directly to the work of Task 8, in which a lock capacity model will be used in an iterative manner to determine the total mix of improvements required to meet GL/SLS demand through the year 2050.

### 3. DESCRIPTION OF THE LOCKING PROCESS

#### 3.1 An Overview of the Locking Process

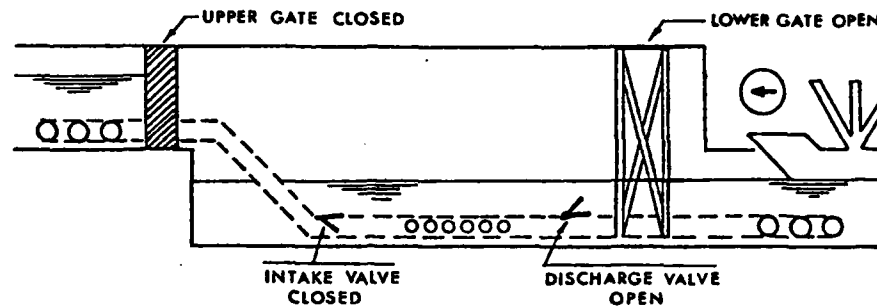
Locks were placed on the Great Lakes/St. Lawrence Seaway System to allow passage of vessels where the natural conditions of rapids and water falls made navigation impossible. The locks allow navigation through the waterways while maintaining relatively large differences in water level between the upstream and downstream sides of the lock. The locks also allow for the installation and operation of several hydroelectric power generating stations without preventing vessel use of the System.

Vessels using the locks on the GL/SLS System range in type and size from pleasure craft as small as 20 ft long to ocean and lake carriers 730 ft long and 76 ft wide in the St. Lawrence River and Welland Canal Locks, up to lake carriers 1,000 ft long and 105 ft wide at the Soo Locks. The details of the locking process will vary depending on the type and size of the vessel, weather conditions and lockage demand, and on the individual lock characteristics. However, the general locking process is always the same.

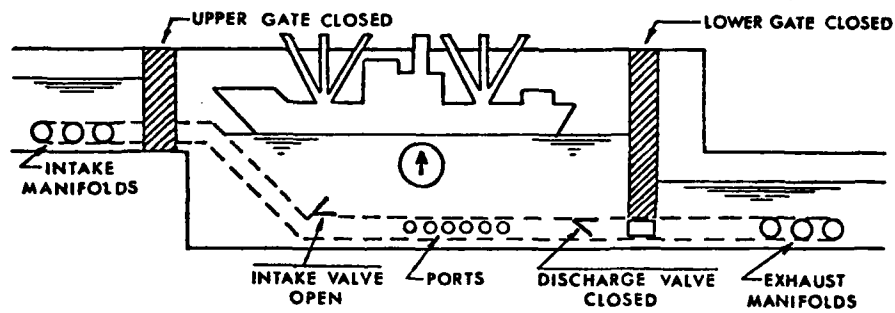
A basic lock operating cycle is illustrated in Figure 3. When a vessel reaches a lock approach, it will either be told by the lockmaster to proceed into the lock or it will moor alongside the approach wall until permission is received to enter the lock. The vessel must wait if the lock is occupied, if the lock is being recycled (turn back), or if there are other vessels waiting first.

After being given the go-ahead, the vessel will proceed into the lock at a very slow rate of speed as instructed by the lockmaster, and as dictated by the locking procedures for that particular lock. When the vessel has entered the lock, it will be moored. One or more vessels may be brought into the lock if the vessel sizes permit a tandem or multiple vessel lockage. Once the vessel(s) are in place, the rearward gates of the lock will be closed. The required valves will be opened and the chamber will be emptied (dumped) or filled depending on whether the vessel(s) are transiting from higher to lower, or lower to higher water. This process is called chambering. When the new water level has been reached, the forward gates will be opened, the mooring lines will be cast off, and the vessel(s) will proceed out of the lock.

### STEP 1; VESSEL ENTERING THE LOCK



### STEP 2; FILLING OF THE LOCK



### STEP 3; VESSEL LEAVING THE LOCK

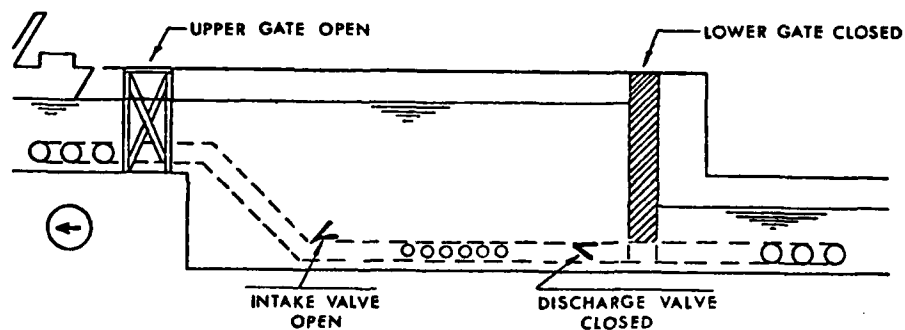


FIGURE 3 BASIC LOCKING PROCESS

### 3.2 Factors Affecting the Locking Process

The time required to process a vessel through a lock (locking time) can be broken down into a small or large number of components. One of the more elementary breakdowns consists of three components as follows:

- Entrance Time - Time from vessel arrival to vessel mooring inside the lock;
- Chambering Time - Time required to close the rearward gate, empty or fill the lock, and open the forward gates;
- Exit Time - Time from completion of chambering until the lock is ready to accept another vessel.

The length of the locking time is dependent upon individual lock characteristics, vessel characteristics, the preceding lock cycle, weather conditions, level of traffic, and equipment failures. Improper positioning of the vessel to be locked next would cause additional delays.

The lock characteristics mainly affect chambering time. Gate opening and closing times are basically functions of the operating machinery. Dump/fill times are functions of the size of the chamber and the lock culverts. In general, differences in chambering time because of differences between lock designs are negligible. However, during extended season operations, lock designs can affect lock chambering times.

Vessel characteristics will not affect dump/fill times because the amount of water which must be moved into or out of the lock is independent of vessel size. Large vessels, especially those approaching maximum vessel size for the lock, will increase entrance and exit times. The larger ships must move slower and will require extra maneuvering time in order to safely enter and exit the lock and clear other vessels. Specific vessel classes may require special handling procedures.

During periods of equal amounts of upbound and downbound traffic, vessels can be locked "on the fly". That is to say, vessels are locked in alternate upbound and downbound directions, eliminating the need for turnback lockages. When traffic is primarily in one direction, turn-back lockages are required. After a vessel is locked through, the gates must be turned back and the lock must be emptied or filled so that the next vessel may be taken from the same direction.



Adverse weather conditions may increase locking times or cause shutdown of the locks altogether. During early or late season operations, large accumulations of ice in the lock and lock throat may require separate ice lockages. Fog may cause lock shutdown because of visibility problems. High winds may make vessels with large broadside areas unmanageable, causing them to be temporarily prohibited from using the lock.

Maintenance schedules have been arranged to minimize their impact on locking times; however, temporary delays may still occur because of equipment failure. The rate of these failures may increase when the navigation season is extended into winter operations.

### 3.3 Locking Procedures at the Soo Locks

The Soo Locks consist of five parallel locks: Poe, MacArthur, Sabin, Davis, and Canadian. The MacArthur Lock handles most loaded ships up to 730 ft long (767 ft with special locking procedures) and 75 ft wide. The Sabin and Davis Locks handle most ballasted ships up to 826 ft long and 75 ft wide. The Poe Lock handles any ship which cannot fit in the Sabin, Davis, or MacArthur Locks, up to the maximum size of 1,000 ft long and 105 ft wide, and any smaller vessel on a first-come, first-serve basis. The Canadian Lock handles the majority of the pleasure craft and small vessels with shallow drafts.

Each lock has its own pier which can accommodate several ships in a queue. Signal lights, operated by the lockmaster, control the flow of traffic at the Soo Locks. As vessels approach the correct lock based on the lock use criteria stated above, they are directed by means of the signal lights and radio communication. Vessels stop at approach points indicated by signs on the approach piers until they are authorized to proceed into the lock or to the next approach point. Vessel speed limits are 2.5 mph while approaching the canal and lock, and 6 mph while exiting the canal and lock.

Whenever possible, on the fly lockages are performed. However, cargo flows through the Soo are highly one-directional from Lake Superior. Since different locks are used for ballasted and loaded traffic, this policy cannot be adhered to much of the time.

The Soo Locks, more than any other lock on the GL/SLS System, operate under extended winter navigation season conditions.

Ice control equipment is in use; however, ice lockages are sometimes required to clear ice from the upstream approaches.

### 3.4 Locking Procedures at the Welland Canal Locks

The Welland Canal consists of eight locks in a series, all with capacities to handle ships up to 730 ft long and 76 ft wide. No separate facilities exist for pleasure craft at the Welland Canal.

Each lock has approach walls with up to three limit-of-approach signs on each to indicate mooring locations for vessels waiting to enter the lock. The vessels receive proceed or wait instructions by means of signal lights mounted on the limit-of-approach signs. In addition to these limit-of-approach lights, there is a panel of signal lights at each lock which gives the exact status of the lock and the time left before it will be available to the next ship.

A central control area with closed circuit television, display boards, and a communications network is used at the Welland Canal to aid in controlling the movement of traffic through the Canal. This system was installed in the mid-1960's and resulted in an increase in Welland Canal capacity.

Locks 4, 5, and 6 at Welland are flight locks. Once a ship enters the three lock system, it must transit all three locks before the next ship may enter. These locks are twinned, however, permitting parallel traffic. Large ships in these three locks are instructed by means of a portable radio telephone which is placed onboard each ship over 625 ft in length.

Lock 8 in the Welland Canal is a guard lock. When water level conditions permit, a walk-through procedure is used. The ship does not moor inside the lock. Rather the vessel will proceed through the lock under its own power with its mooring lines carried by lock personnel.

Large ships with a wet cross-sectional area greater than 1,600 ft<sup>2</sup>, heading downbound through Locks 1, 2, 3, 7, and 8, may receive longitudinal hydraulic assistance during lock exit. This feature increases ship speed out of the lock and reduces locking time. Smaller, upbound ships entering Locks 1, 3, and 7 may be aided by lateral hydraulic assistance or the prefill operation. Single lockage ships with beams less than 66 ft may receive lateral hydraulic assist, and single lockage ships less than 650 ft long may receive the prefill operation. These

features reduce lock entry time. Ships less than 590 ft in length moving through Locks 1, 2, 3, and 7 may receive the predump operation to reduce the lock dumping time. None of these aforementioned features may be used with pleasure craft.

### 3.5 Locking Procedures at the St. Lawrence River Locks

The St. Lawrence River Locks are a series of seven locks extending from Montreal to Lake Ontario, all with capacity to handle ships 730 ft long and 76 ft wide. Five locks, the St. Lambert, Cote Ste. Catherine, Lower Beauharnois, Upper Beauharnois, and Iroquois, are operated by Canada and two locks, the Snell and Eisenhower, are operated by the United States. None of the locks have separate facilities for pleasure craft.

The Canadian operated locks in the St. Lawrence River are operated in the same manner as the Welland Canal Locks. The Iroquois Lock is a guard lock similar to Welland Lock 8. The walk-through procedure is used at the Iroquois Lock whenever possible. The other four Canadian operated locks are lift locks. None of the special locking time reduction features are available at these locks. Radio controls have not been implemented, and the ships are directed by means of the same signal light system as is used at the Welland Canal.

The United States operated locks both have approach walls with two limit-of-approach signs on each to indicate waiting positions for vessels preparing to enter the lock. There are eight berthing stations along the approach wall at which waiting ships can moor. Vessels with beams less than 50 ft must tie up behind the limit-of-approach signal which is located at Berth B-3. Vessels with beams less than 75 ft must tie up behind limit-of-approach sign 2 which is located at Berth B-5.

Traffic at each United States Lock is controlled by means of a single panel of signal lights for each direction. The lights indicate either the lock is not ready, the lock is being prepared, or the lock is ready and the ship can proceed into the lock. Mooring lines at the tie-up walls are handled by lock personnel at all of the St. Lawrence River Locks. No special locking time reduction features are available at the Snell and Eisenhower Locks.

## 4. ANALYSIS OF LOCKING TIME DATA

### 4.1 Introduction

The overall purpose of this section of the report is to present an analysis of the locking time data which is available, and recommendations regarding the locking time data base to be used in the remainder of this study for the SOO, WELLAND CANAL, and ST. LAWRENCE RIVER Locks. Before proceeding with that presentation, brief introductory comments are presented on the importance of having accurate and complete locking time data available for studies of system capacity.

From the standpoint of lock capacity, which is the purpose of this study, accurate locking time data provides the only tool available for assessing the lock capacity in terms of vessel transits and/or cargo tonnage throughput, both for the current system and for the various lock improvement scenarios. The locks provide a service to the shippers and, in a very real sense, that service can be measured in terms of the time the lock is devoted to processing a particular vessel. As a result, the method of increasing lock capacity without major structural modifications or new locks is to reduce the lock service time required to process a ship through the lock. To accurately assess the increase in lock capacity expected to be obtained through the proposed improvements, one must have an accurate breakdown of the total lock service time in terms of individual components. One can use this information to assess where the biggest benefits of increased capacity can be derived by reducing individual locking time components. For example, if the gate opening and closing times are 2 minutes each of a total lock service time of 40 minutes, the gate opening and closing comprise only 10% of the total time. If proposed lock improvements could reduce the gate opening and closing times by 50%, the total locking time would be reduced to 38 minutes or 5%. On the other hand, if proposed lock improvements could reduce the entrance and exit time by 50%, from 30 minutes to 15 minutes, the total locking time would be reduced to 25 minutes or almost 40%. In terms of capacity, one can estimate as a first approximation the increase in capacity as being proportional to the reduction in locking time. Thus, for these two examples, the increases in capacity would be 5% and 38% respectively. If the cost of these improvements were the same, the greater benefit in terms of capacity and reduced locking time would be gained by funding the improvement aimed at reducing the lock entrance and exit times rather than the gate opening and closing times. Without a reasonably accurate breakdown of locking time components, potential benefits

in terms of additional lock capacity due to improving the system performance, can only be assessed in an overall qualitative manner rather than a specific quantitative manner.

With this brief introduction, the following two sections of this report are directed towards discussing the present status of locking time data for the SOO, WELLAND CANAL, and ST. LAWRENCE RIVER Locks, and a recommended locking time data base for each lock for use in the remainder of the study.

#### 4.2 Existing Locking Time Data Base

The purpose of this section of the report is to present the current status of locking time data as it is currently collected at the SOO, WELLAND CANAL, and ST. LAWRENCE RIVER Locks. In discussing the current status, the idealized goal would be to present reams of detailed locking data for each lock system which could then be thoroughly analyzed. However, the truth is that, with the exception of the Welland Canal, this is not the case.

Currently, existing lockage time data is available in two forms: raw, uncut data in the form of lock transit records or original observation data and analyzed data developed from the raw data. When collecting any type of raw data, such as locking time data, three questions arise: What type of data should be collected? When should the data be collected? and How much data should be collected? Ideally, locking time data should be collected for each locking time component outlined in the next section of the report and cataloged as to vessel class, direction, and cargo carried. In order to answer the second question, the data should be collected in the warmer peak traffic months since the GL/SLS System does not operate on a year-round basis, and capacity, if it occurs, will occur during the peak normal season months. Finally, the answer to the third question can be an expensive proposition. In order to develop a statistically significant data base, at least one full season of data collection is required. In fact, at the Welland Canal where they have over a year of detailed data collection, they believe that additional data are required. For the long term, a systematic data collection procedure should be instituted to obtain a large enough data base under various operational procedures, traffic levels, and patterns to allow detailed investigation of capacity improvement alternatives.

In summary, the current status of locking time data for the SOO, WELLAND CANAL, and ST. LAWRENCE RIVER Locks is as follows:

SOO Locks: As can be seen from the record shown in Figure 4, the data available from the SOO Locks are limited, consisting of an arrival time and a departure time only for each vessel. These times correspond to bow over the entrance sill and stern over exit sill. Therefore, the two components of approach time and exit time are not recorded.

ST. LAWRENCE RIVER Locks: For the ST. LAWRENCE RIVER Locks, the situation is much the same as the SOO as can be seen in Figures 5 and 6. The Canadian lock operators document arrival time and departure time, while the American lock operators at the Snell and Eisenhower locks document arrival time, enter time, and departure time. This is somewhat more helpful but is still incomplete for a thorough locking time analysis.

WELLAND CANAL Locks: The situation at the WELLAND CANAL is very different from the SOO and ST. LAWRENCE RIVER. Figures 7 through 9 are analysis summaries developed by the SLSA from the data base collected for the Welland Canal Lock model. These summaries are extensive and can answer most questions about locking times for the Welland Canal Locks.

#### 4.3 Recommended Locking Time Data Base

In general terms, the lock service time ( $t_\ell$ ) for normal season operations can be expressed as:

$$t_\ell = t_{\text{approach}} + t_{\text{entry}} + t_{\text{process}} + t_{\text{chamber exit}} + t_{\text{throat exit}}$$

where

$$t_{\text{process}} = t_{\text{gate closing}} + t_{\text{securing}} + t_{\text{dump/fill}} + t_{\text{gate opening}} + t_{\text{unsecuring}}$$

and

$$t_\ell = \text{time required to lock a ship (min)}$$

$$t_{\text{approach}} = \text{time for a ship to move from clear point to point where bow is over entrance sill (min)}$$

$$t_{\text{entry}} = \text{time from point of bow over sill to point where entrance gates can close (min)}$$

$$t_{\text{gate closing}} = \text{time for entrance gates to close (min)}$$

REGISTER OF VESSEL TRAFFIC THRU LOCKS														Name of Waterway										WEST				Date																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
No.	Name of Vessel	Draft		Arrive		MacArthur Lock		Poe Lock		Davis Lock		Sablin Lock		Leave End Pier	Delays, Etc.	Bound		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages		Lockages	

FIGURE 4. SAMPLE SGO LOCK RECORD

# FEUILLE DE JOURNAL D'ÉCLUSE SIMPLE SINGLE LOCK LOG RECORD

MATINÉE ÉCLUSE / LOCK DAY: 27-24-1941  
 NIVEAU DE L'EAU / WATER LEVEL: 14.13 / 14.70  
 HIGHER / LOWER: HIGH / LOW

NAVIRE - VESSEL	NOM NAME	HEURE DE L'ARRIVÉE / TIME OF ARRIVAL				HEURE DU DÉPART / TIME OF DEPART				REMARQUES REMARKS	HEURE DE L'ARRIVÉE TIME OF ARRIVAL	HEURE DU DÉPART TIME OF DEPART	AVANT FOR	APRÈS AFT
		1	2	3	4	5	6	7	8					
1073	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1074	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1075	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1076	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1077	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1078	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1079	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1080	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1081	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1082	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1083	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1084	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1085	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1086	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1087	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1088	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1089	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		
1090	ST. LAWRENCE	U	R	14	14	14	14	14	14	CHANGÉ PAR 2147	14	14		

FIGURE 5. SAMPLE ST. LAWRENCE RIVER CANADIAN LOCK RECORD.





# WELLAND CANAL SINGLE LOCK ANALYSIS

PAGE 1

LOCK COMPARISON

04/04 TO 12/31 1977 6519 HOURS

DESCRIPTION	LOCK 1		LOCK 2		LOCK 3		LOCK 7		LOCK 8	
	UP	DN	UP	DN	UP	DN	UP	DN	UP	DN
WEATHER STALLED TIME	32 01	3 21	23 27	23 43	35 27	14 20	5 15	3 37	10 59	20 35
TOTAL STALLED TIME	194 24	31 21	252 23	46 02	281 49	149 59	54 14	60 05	214 16	504 12
OPERATING DELAY (TOTAL)	23 29	11 30	14 22	11 06	11 30	9 43	8 33	33 31	33 41	24 14
OPERATING DELAY / LOCKAGE	0.5	0.2	0.3	0.2	0.2	0.2	0.2	0.7	0.7	0.5
LOCK OPERATING TIME / LOCKAGE	13.7	12.6	13.4	12.4	13.1	13.0	12.7	11.0	6.3	5.2
VESSEL TIME / IN-OUT LOCKAGE	24.6	21.7	22.9	22.4	22.7	22.6	20.5	27.2	30.5	34.5

## LOCK CYCLES

	LOCK 1	LOCK 2	LOCK 3	LOCK 7	LOCK 8
FLY CYCLE	87.6	68.1	45.5	74.1	66.7
PASSING ENTRY CYCLE	75.2	73.5	74.0	83.7	82.1
HEAVY BALANCED CYCLE	76.7	74.2	74.9	83.9	82.1
EXPECTED LOCKAGES / DAY	37.5	38.8	38.5	34.3	35.1
MOORED CYCLE	73.6	70.3	71.1	81.5	82.1
IN - OUT CYCLE	73.5	71.6	72.0	80.3	77.7

(4.1 INDICATES A SMALL NUMBER OF OBSERVATIONS)

## LOCK 1 SUMMARY

VESSELS & LOCKAGES	UP	DN	TOTAL	LOCKAGE MIX	UP	DN	OVERALL
INLAND VESSELS	2528	2491	5019	REGULAR INLAND	41.38	39.13	40.25
OCEAN VESSELS	913	911	1824	REGULAR OCEAN	27.45	27.73	27.68
VESSEL LOCKAGES	3072	2995	6067	SPECIAL	23.98	24.68	24.28
TURNBACK LOCKAGES	1244	1321	2565	NORMAL INLAND	3.13	3.81	3.58
				OTHER MULTIPLE	4.38	4.78	4.58

FIGURE 7. SAMPLE WELLAND CANAL LOCK SUMMARY RECORD - PART I

WELLAND CANAL SINGLE LOCK ANALYSIS														
LOCK 1		PERIOD SUMMARY		ANALYSIS PERIOD REQUESTED		17/04/04/0001 TO 17/12/11/2400		ACTUAL ANALYSIS PERIOD		17/04/04/0001 TO 17/12/10/2125		PAGE 2		
DESCRIPTION		REG-INLAND		NORMAL-TANDEM		SPECIAL		MFG-OCEAN		DTM-MULTIPLE		OVERALL		
STALLED DELAY / LOCKAGE		UP	DN	UP	DN	UP	DN	UP	DN	UP	DN	UP	DN	UP
E F 1 ON THE FLY		10.4	9.3	16.3	11.0	14.0	12.4	13.4	10.4	16.3	16.6	12.4	10.4	
(CASES)		(745)	(545)	(4)	(23)	(209)	(444)	(306)	(530)	(23)	(56)	(887)	(1608)	
M P2 1 PASSING AT LA2		13.1	10.5	14.3	11.1	16.3	14.3	15.4	12.0	16.3	16.0	15.5	12.1	
(CASES)		(187)	(272)	(3)	(13)	(127)	(177)	(151)	(166)	(10)	(11)	(476)	(842)	
T P3 1 PASSING AT LA3		17.4	14.7	22.0	15.0	22.0	17.7	22.0	16.9	25.3	20.6	20.1	16.1	
(CASES)		(116)	(133)	(4)	(2)	(61)	(59)	(60)	(65)	(4)	(6)	(274)	(267)	
R M 1 MOORED		12.4	8.4	15.7	10.8	18.9	12.7	20.1	12.9	12.0	9.5	15.4	10.0	
(CASES)		(175)	(130)	(60)	(60)	(145)	(35)	(143)	(35)	(66)	(40)	(879)	(104)	
Y J1 1 TURNBACK AT LA1		9.3	7.3	13.4	10.2	15.4	13.4	13.0	8.2	17.0	13.8	12.1	9.2	
(CASES)		(59)	(36)	(7)	(5)	(38)	(7)	(25)	(5)	(2)	(6)	(131)	(61)	
TM 1 TURNBACK MOORED		12.4	6.9	15.7	9.6	17.0	14.0	17.1	9.1	25.0	7.8	15.5	6.0	
(CASES)		(189)	(55)	(18)	(11)	(113)	(6)	(78)	(56)	(26)	(11)	(423)	(89)	
E XF 1 ON THE FLY		7.0	7.6	8.8	6.9	9.8	9.8	9.9	10.1	6.7	7.9	8.7	8.5	
(CASES)		(172)	(168)	(21)	(19)	(165)	(81)	(193)	(61)	(40)	(27)	(791)	(356)	
X XP 1 PASS AT LA2 OR LA3		9.4	9.2	8.9	4.7	10.9	11.1	11.5	11.4	6.9	7.3	10.4	10.2	
(CASES)		(173)	(294)	(18)	(25)	(233)	(144)	(286)	(222)	(19)	(27)	(929)	(752)	
I XM 1 MOORED		8.4	9.3	9.9	9.6	11.4	11.6	11.5	12.0	7.9	8.7	10.1	10.7	
(CASES)		(94)	(311)	(27)	(45)	(70)	(216)	(90)	(271)	(23)	(36)	(304)	(879)	
T XT 1 TURNBACK NEXT		7.4	7.5	9.5	8.8	9.4	9.4	9.2	10.0	6.5	8.2	8.4	6.7	
(CASES)		(431)	(398)	(30)	(25)	(265)	(257)	(273)	(276)	(49)	(52)	(1046)	(1008)	
M CLOSE-UP & SECURE / LOCKAGE		2.4	1.7	3.0	1.5	2.9	2.6	3.2	1.9	2.5	1.5	2.9	2.0	
WATER TIME / LOCKAGE		9.7	9.7	10.0	9.8	10.0	9.9	9.6	9.4	10.0	9.8	9.8	9.7	
OPENING TIME / LOCKAGE		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
OPERATING TIME / LOCKAGE		13.5	12.4	14.0	12.3	14.0	13.5	13.8	12.4	13.5	12.3	13.7	12.6	
OPERATING DELAY / LOCKAGE		0.4	0.2	0.3	0.6	0.3	0.1	0.2	0.2	0.3	0.6	0.5	0.2	
IN-VES TIME/P2 ENTRY		13.3	10.5	14.3	11.1	14.3	14.3	15.8	12.0	18.5	17.0	15.5	12.1	
OUT-VES TIME/XP EXIT		9.4	9.2	8.9	8.7	10.9	11.1	11.5	11.4	6.6	7.3	10.4	10.2	
WORKING TIME/LOCKAGE		37.0	32.3	37.5	32.7	43.5	39.0	41.3	36.0	38.9	37.2	40.1	35.1	
PASSING ENTRY CYCLE		69.3		70.2		82.5		77.3		76.1		75.2		
IN-VES TIME/P2/P3-M ENTRY		13.7	11.0	16.0	11.0	19.2	14.8	19.0	13.5	13.5	12.0	16.4	12.5	
OUT-VES TIME/XP-M EXIT		9.2	9.2	9.5	9.3	11.0	11.4	11.5	11.7	7.2	8.1	10.3	10.5	
WORKING TIME/LOCKAGE		47.2	32.6	39.8	33.2	44.5	39.8	44.5	37.4	34.5	33.0	40.9	35.4	
HEAVY BALANCED CYCLE		70.0		73.0		84.3		82.3		67.5		74.7		
IN-VES TIME/P2/P3-M ENTRY		12.4	10.2	14.0	11.0	17.3	13.3	16.7	11.6	14.1	14.1	15.1	11.6	
OUT-VES TIME/XP-M EXIT		8.6	8.9	9.3	8.8	10.4	11.1	10.9	11.5	7.0	8.1	9.7	10.1	
WORKING TIME/LOCKAGE		47.4	31.7	39.4	32.7	42.2	34.0	41.6	35.7	34.9	35.1	39.0	34.4	
IN - OUT CYCLE		67.4		72.3		80.2		77.3		70.0		73.5		
TIME UTILIZATION		UP	DN	OVERALL	VESELS & LOCKAGES	UP	DN	TOTAL	THICK LOCKAGES	UP	DN			
WORKING / TOTAL		53.7%	54.3%		NI. OF INLANDS	2528	2491	5019	NO. OF TB LOCKAGES	1244	1391			
STALLED / TOTAL		5.3%	3.5%		NI. OF OCEANS	913	911	1824	WATER TIME / TB LKG	10.0	10.0			
MO-VESSEL / TOTAL		34.9%	30.4%	33.1%	MODULAR LOCKAGES	2112	2001	4113	ACTUAL TN TIME/TB LKG	10.9	10.0			
ACTUAL TD / TOTAL		6.1%	6.4%	7.1%	SPECIAL LOCKAGES	733	736	1471	EFFECTIVE TD TIME/LKG	7.4	7.1			
					MULTIPLE LOCKAGES	227	256	483						
					TOTAL VESSEL LKGS	1072	2495	4067						

FIGURE 8. SAMPLE WELLAND CANAL LOCK SUMMARY RECORD - PART 2



$t_{\text{securing}}$  = time for a ship to secure (min)  
 $t_{\text{dump/fill}}$  = time for a lock to dump or fill (min)  
 $t_{\text{gate opening}}$  = time for exit gates to open (min)  
 $t_{\text{unsecuring}}$  = time for a ship to unsecure (min)  
 $t_{\text{chamber exit}}$  = time for stern of ship to pass over exit sill (min)  
 $t_{\text{throat exit}}$  = time for ship to move from its stern over sill to when the ship has passed the exit clear point and another ship can begin the locking process from the other direction.

As discussed in the previous section, one would like to have reams of data for the above locking time components which would then be analyzed to determine a mean frequency distribution for each component. In reality, this data does not exist for any system other than the WELLAND CANAL. In order to obtain the required time component data for each of the lock systems, the following approach was taken.

WELLAND CANAL Locks: The St. Lawrence Seaway Authority (SLSA) has done a significant amount of lock record analysis to generate mean locking times and the associated standard deviations by vessel class and direction. The results of that analysis for one full year of lock records is presented in Tables 1 and 2. Based on conversations with SLSA personnel, the comment was made several times that while this was the best data available, they felt they needed more than a full year of data to have a statistically significant data base. In summary, based on their analysis, Lock 7 was found to be the most constraining lock in terms of locking time, while Locks 1, 2, and 3 had almost the same locking time (approximately 5 to 7 minutes less than that at Lock 7), and the total locking time at the flight locks (Lock 4, 5, 6) was approximately 30 to 35 minutes depending on the ship class.

ST. LAWRENCE RIVER Locks: At the St. Lawrence River Locks, as discussed in the previous section, data on locking times are not as complete and detailed as those available for the Welland Canal. Following the recommendation of the SLSA and SLSDC personnel, the locking times of the St. Lawrence River Locks are assumed to be the same as those of the nonconstraining locks (Lock 1, 2, 3) in the Welland Canal. A summary of the locking time data for the St. Lawrence River Locks is presented

TABLE 1 LOCK TIMES FOR THE WELLAND CANAL CONSTRAINING LOCK

Vessel Class	Gate Open	Gate Closed	Dump/ Fill	$t_{approach}$		$t_{entry}$		$t_{in\ lock}^*$		$t_{chamber\ exit}$		$t_{throat\ exit}$		$t_{total}$		$\sigma$	
				Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound
IV	1	1	9	9	9	5	5	11	13	4	4	6	8	35	39	2.7	2.8
V	1	1	9	9	9	5	5	11	13	4	4	6	8	35	39	2.7	2.8
VI	1	1	9	12	13	7	7	12	13	6	6	8	8	45	47	3.5	3.8
VII	1	1	9	14	13	7	8	12	13	6	6	8	8	47	48	4.1	4.1

NOTES: \*includes column 1, 2, 3, and securing and unsecuring.

SOURCES: All data was developed from "Welland Canal Single Lock Analysis" summary sheets. The constraining lock was considered to be Lock 7.

TABLE 2 LOCK TIMES FOR THE WELLAND CANAL NONCONSTRAINING LOCKS

		Total Locking Time														
Vessel Class	Gate Open	Gate Closed	Dump/ Fill	$t_{\text{approach}}$		$t_{\text{entry}}$		$t_{\text{in lock}}^*$		$t_{\text{chamber exit}}$		$t_{\text{throat exit}}$		$t_{\text{total}}$		$\sigma$
				Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	
IV	1	1	9	7	7	5	5	13	13	4	4	5	5	34	34	2.7 2.7
V	1	1	9	7	7	5	5	13	13	4	4	5	5	34	34	2.7 2.7
VI	1	1	9	7	9	7	7	13	13	6	6	6	5	39	40	2.8 2.8
VII	1	1	9	8	9	7	8	14	13	6	6	6	5	41	41	3.0 3.0

NOTES: \*includes column 1, 2, 3, and securing and unsecuring.

SOURCES: All data was developed from "Welland Canal Single Lock Analysis" summary sheets. The constraining locks were Locks 1, 2, and 3.

in Tables 3 and 4. The distribution of locking times for lakers and oceangoing vessels greater than 492 feet LOA downbound at Snell Lock is shown in Figure 10. While this data sample is very limited, it does provide a qualitative picture of the distribution for oceangoing and laker traffic.

Soo Locks: Similar to the St. Lawrence River situation, data on locking times at the Soo are not as complete and detailed as that available for the Welland Canal. At the Soo, the only locking time data collected are the times from when the bow passes over the entrance sill until when the stern passes over the exit sill. Data on entrance and exit times are not available. In order to estimate these entrance and exit times, conversations were held with the lock operators to determine where the clearing points were defined and what practical assumptions could be made in order to obtain the data needed. Based on those discussions, it was decided to estimate the entrance and exit times by assuming that the average speed of advance of vessels entering the lock is approximately 1.0 mph and the average speed of advance of vessels leaving the lock is approximately 2.0 mph. Using this approach, along with locking data from the Sabin-Davis Lock Model and gathered by Penn State at the Soo, the locking time data presented in Tables 5 and 6 were derived. The distribution of locking times for MacArthur class ships (730 x 75) downbound through the MacArthur Lock, and Poe class ships downbound through the Poe Lock are shown in Figures 11 through 13. As was the case for the St. Lawrence River, this data sample is very limited but it does provide a qualitative picture of the lockage time distribution for ships using the Soo Locks.



TABLE 3 LOCK TIMES FOR THE SLR CONSTRAINING LOCKS

Vessel Class	Total Locking Time									
	1		2		3		4		5	
	Gate Open	Gate Closed	Dump/Fill	t <sub>approach</sub>	t <sub>entry</sub>	t <sub>in lock</sub>	t <sub>chamber exit</sub>	t <sub>throat exit</sub>	t <sub>total</sub>	σ
				Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	
IV	2	2	7	7	7	5	5	5	34	2.7
V	2	2	7	7	7	5	5	5	34	2.7
VI	2	2	7	7	9	7	7	6	39	2.8
VII	2	2	7	8	9	7	8	6	41	3.0

NOTES: \* includes column 1, 2, 3 and securing and unsecuring.

SOURCES: Following the recommendations of SLSA and SLSDC personnel, the locking times for the SLR constraining lock was assumed to be the same as the Welland Canal nonconstraining locking times.

1, 2, 3: Peter, J. J. and T. V. Kotras, "Simulation of Lock Operations During Winter Ice Months," Proceedings of the Third International Symposium on Ice Problems, International Association of Hydraulic Research, Nov. 1975, pp. 49-58.

TABLE 4 LOCK TIMES FOR THE SLR NONCONSTRAINING LOCK

Vessel Class	1	2	3	4	5		6		7		8		9			
					Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound	Down-bound	Up-bound
	Gate Open	Gate Closed	Dump/Fill	t <sub>approach</sub>	t <sub>entry</sub>	t <sub>in lock</sub>	t <sub>chamber</sub>	t <sub>throat</sub>	t <sub>exit</sub>	t <sub>total</sub>	t <sub>exit</sub>	t <sub>total</sub>	t <sub>exit</sub>	t <sub>total</sub>	t <sub>exit</sub>	t <sub>total</sub>
IV	2	2	7	5	5	13	4	4	4	31	4	31	31	31	2.3	2.3
V	2	2	7	5	5	13	4	4	4	31	4	31	31	31	2.3	2.3
VI	2	2	7	6	7	13	6	6	4	36	4	36	36	36	2.7	2.7
VII	2	2	7	6	8	14	6	6	4	37	4	37	37	37	2.8	2.8

NOTES: \*includes column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2, 3: Same as SLR Constraining Lock data.

4, 8: The difference between the SLR constraining and nonconstraining data in columns 4 and 8 approximate the differences between the constraining and nonconstraining data in columns 4 and 8 for the Welland Canal. This is due to the fact that approach and exit times are a function of the amount of usage of the lock.

5, 6, 7: These times are assumed to be functions of vessel class only, therefore they are the same for constraining and nonconstraining locks.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendices-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," Vol. II, ARCTEC, Incorporated Report 478C-4, April 1979.

Figure 10. Distribution of Locking Time for Lakers  
 & Ocean Vessels  $\geq 492'$  LOA at  
 Snell Lock, Downbound

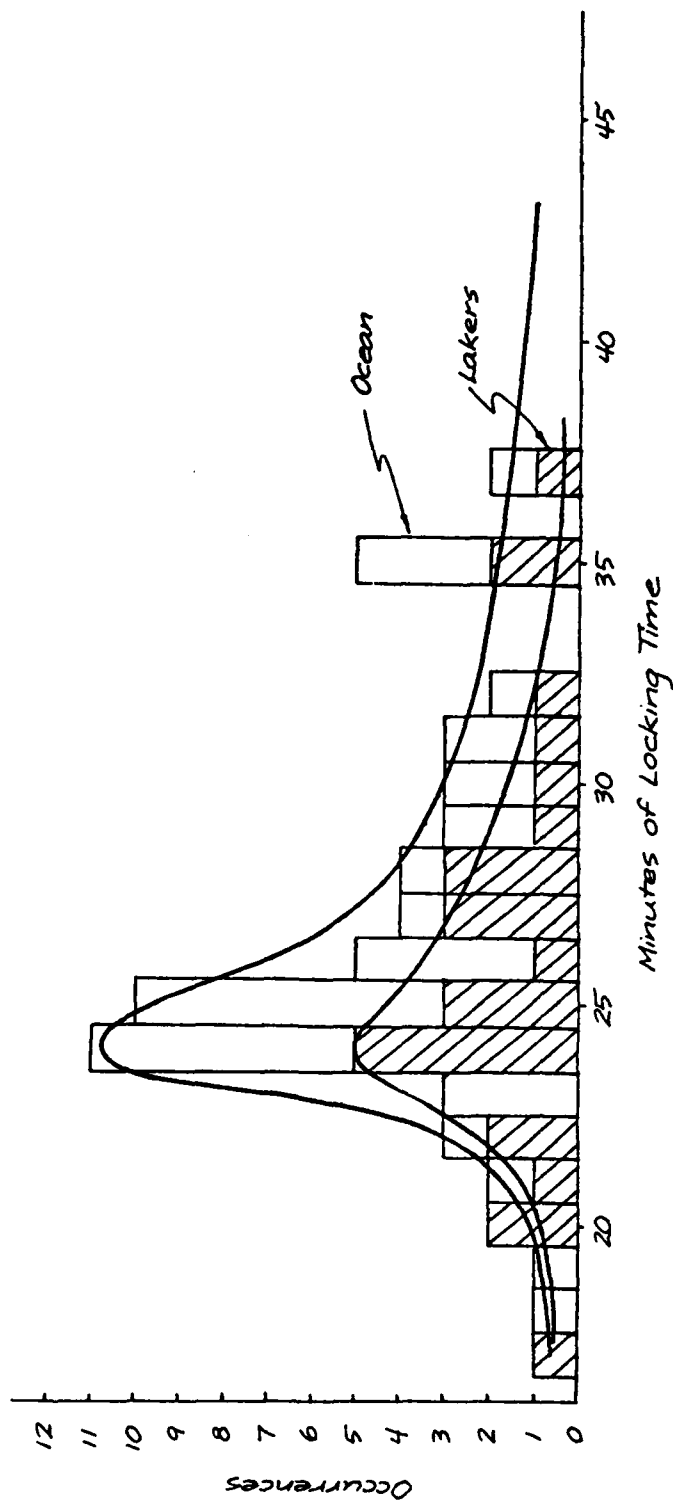


TABLE 5 LOCK TIMES FOR THE MACARTHUR/POE SET OF SOO LOCKS

9

Vessel Class	1 Gate Open	2 Gate Closed	3 Dump/ Fill	4 $t_{approach}$		5 $t_{entry}$		6 $t_{in\ lock}^*$		7 $t_{chamber\ exit}$		8 $t_{throat\ exit}$		Total Locking Time			
				Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	Down- bound	Up- bound	$t_{total}$	$\sigma$		
IV	2	2	7	15	10	12	7	29	28	8	10	9	13	73	68	6.3	9.0
V	2	2	7	17	8	13	8	28	26	8	10	9	13	75	65	6.7	9.3
VI	2	2	6	18	9	14	9	26	23	7	11	9	13	74	65	6.2	9.3
VII	2	2	7	19	7	14	9	28	21	7	11	9	13	77	61	6.3	9.7
VIII	2	2	7	21	6	14	9	23	27	9	11	11	15	78	68	3.5	5.3
IX	2	2	7	26	10	15	10	34	26	14	13	12	14	101	73	6.3	5.7
X	2	2	6	24	9	15	10	43	42	12	14	12	14	106	89	5.5	7.3
XI	2	2	6	26	10	15	10	47	49	14	15	12	14	114	98	5.1	7.3

NOTES: \*includes column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2, 3: Same as reference for SLR constraining locks.

4: Based on the definition of  $t_{approach}$  for this table, and the definitions of long entry and short entry times utilized in the Sabin-Davis model, this column is the difference between the Sabin-Davis short entry time and long entry time data.

5, 7: Comparison between Sabin-Davis short entry time and times calculated for a vessel entering a lock at approximately 1 mph.

6: Comparison of Sabin-Davis chamber cycle time and data developed from Soo lock records.

8: Developed from information obtained from conversations with lock operators.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendixes-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," Vol. II, ARCTEC, Incorporated Report No. 478C-4, April 1979.

TABLE 6 LOCK TIMES FOR THE SABIN-DAVIS SET OF 500 LOCKS

Vessel Class	Total Locking Time																	
	1		2		3		4		5		6		7		8		9	
	Gate Open	Gate Closed	Dump/ Fill	$t_{\text{approach}}$ Down- bound	$t_{\text{entry}}$ Down- bound	$t_{\text{in lock}}$ Down- bound	$t_{\text{chamber exit}}$ Down- bound	$t_{\text{throat exit}}$ Down- bound	$t_{\text{total}}$ Down- bound	$t_{\text{total}}$ Up- bound	$\sigma$	Down- bound	Up- bound	$\sigma$	Down- bound	Up- bound	$\sigma$	
IV	2	2	7	8	5	15	4	3	7	8	39	37	2.8	2.5				
V	2	2	7	9	6	15	5	5	7	8	42	41	3.2	2.8				
VI	2	2	7	9	7	15	6	6	7	8	44	43	2.7	4.0				
VII	2	2	7	10	7	15	6	6	7	9	45	44	2.8	3.5				
VIII	2	2	7	10	8	15	7	7	8	9	48	46	3.0	2.2				

NOTES: \*includes column 1, 2, 3, and securing and unsecuring.

SOURCES: 1, 2, 3: Same as reference for SLS Constraining Locks.

4, 8: Developed from information obtained from conversations with lock operators.

5, 6, 7: Based on vessel entry and exit speeds, and Welland and SLS data.

9: Kotras, T., J. Kim, and J. Jacobi, "Technical Appendices-Great Lakes/St. Lawrence Seaway Lock Capacity Analysis," Vol. II, ARCTEC, Incorporated Report No. 478C-4, April 1979.

Figure 11. Locking Time Distribution for MacArthur Class (730 x 95 max.)  
Ships, Downbound through MacArthur Lock, All  $\geq 25'$  Draft

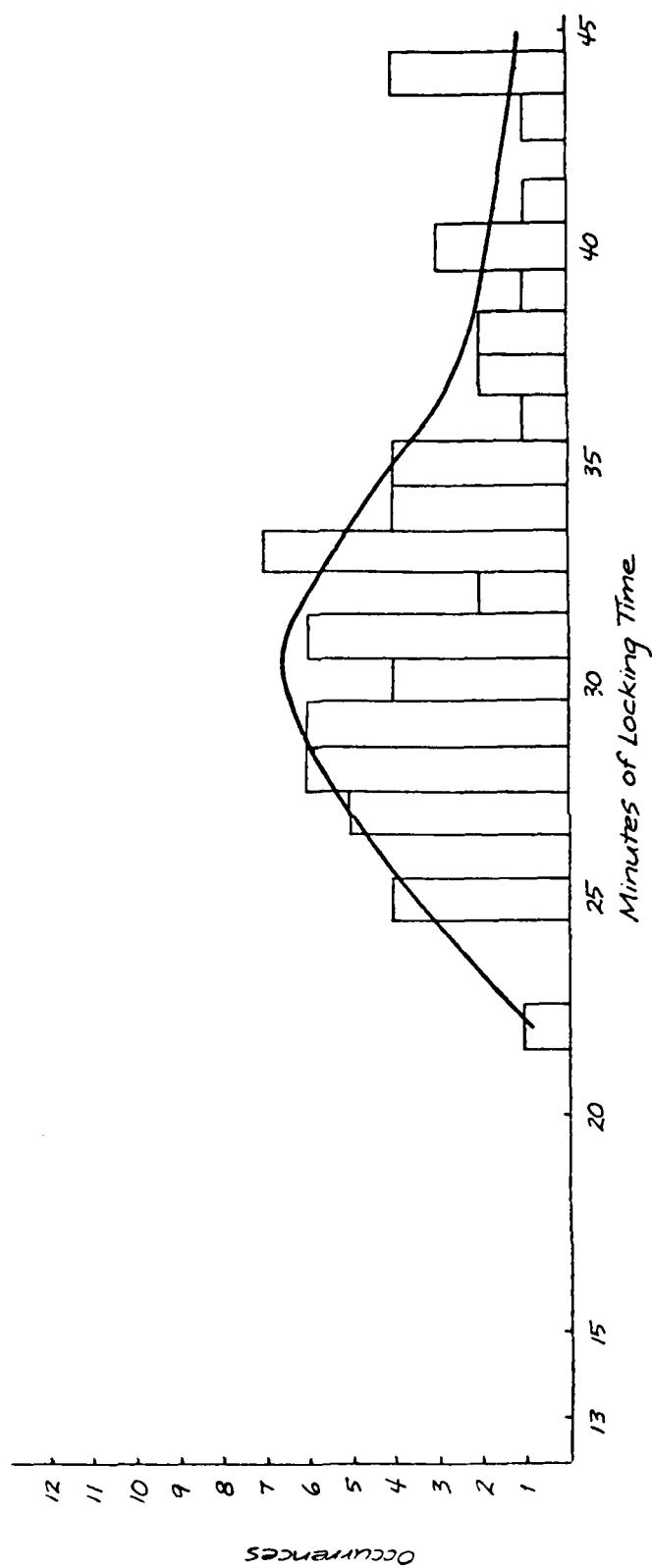


Figure 12. Locking Time Distribution for Poe Class (1100 x 105 max.) ships,  
Downbound. All  $\geq 25'$  Draft.

Areas not shaded indicate 1000' ships.

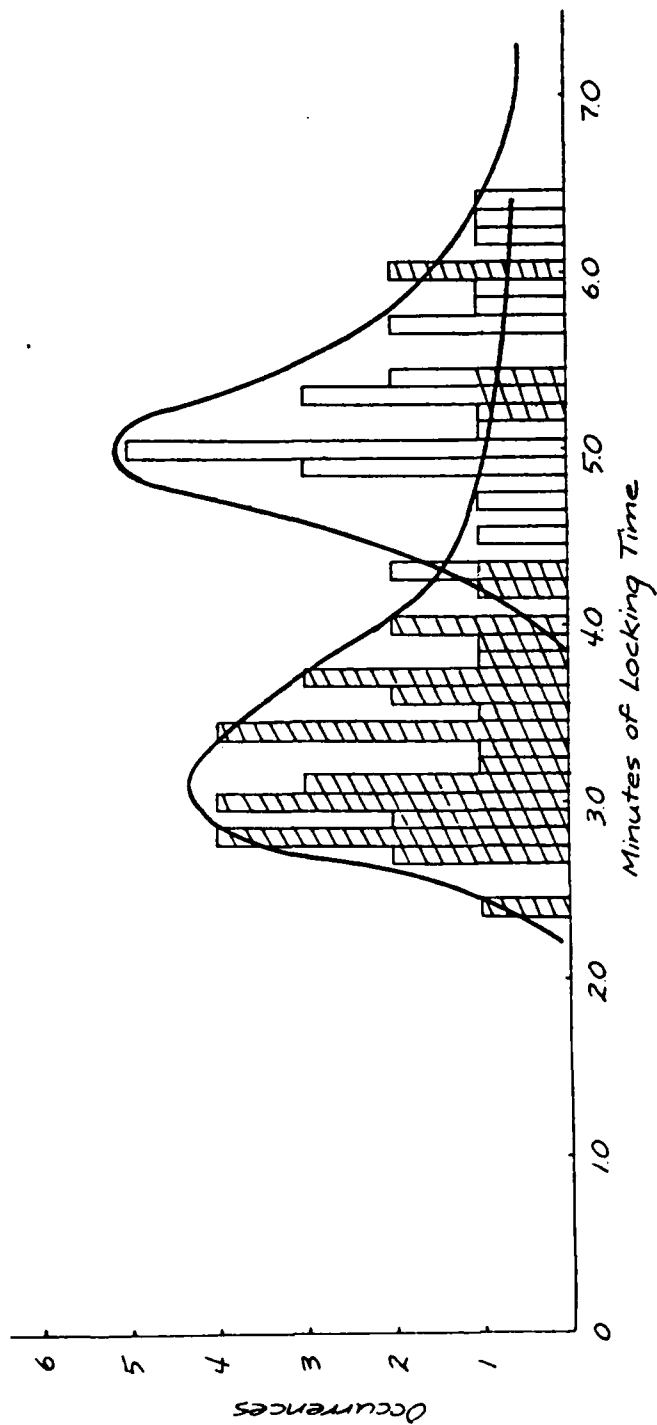
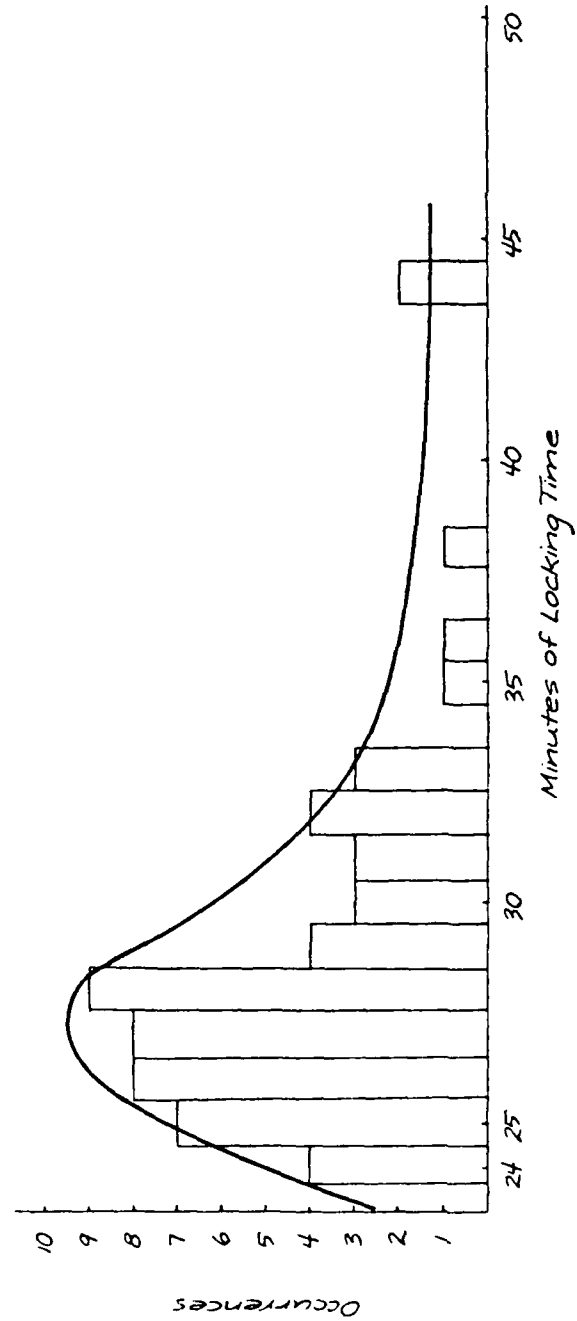


Figure 13. Locking Time Distribution for MacArthur Class (730 x 75 max)  
Ships, Downbound through Poe Lock, All  $\geq 25'$  Draft





## 5. SUMMARY OF REPORTED PROBLEMS WITH EXISTING LOCK SYSTEMS

Interviews were conducted with fleet operators and lock operators to identify any problems being experienced with the present lock systems. This section of the report summarizes the results of these interviews. This summary has been organized by general source, categorized as:

- Great Lakes fleet operators
- Ocean fleet operators
- Lock systems operators.

The specific source of each comment will be identified whenever possible by organization rather than individuals. Individual names are shown, however, on the interview sheets in Appendix A of the fleet mix task report.

### 5.1 Comments from the Great Lakes Fleet Operators

#### Requirement for a Larger System

Fleet operators generally see a requirement for a larger GL/SLS System, including both channels and locks. Fleet operators point out that it would be desirable to be able to load to a depth of 30 to 34 ft (1)\*. Most modern vessels can load to a depth of 29 ft now, but they are prevented from using a greater draft because of the existing depths of the harbors and connecting channels. In addition, ships cannot be built to the most efficient dimensions for carrying capacity because of the size restrictions of the locks and channels (2). Operators generally would like to see a system that has both wider and deeper channels (3).

All large fleet operators using the Soo Locks expressed a need for a second Poe-sized lock. If the Poe Lock were closed for any reason, a large percentage of the commodity carrying capacity of the fleet would be closed out of the system. Fleet operators also believe that the size of the Welland Canal should also be increased to meet the demand for additional capacity in the future (4).

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\* Numbers in parenthesis identify source of comment as listed in Section 5.4 of the report.

### Queuing at Locks

There is a problem with waiting for lock services. Fleet operators report that many times there have been lines of 20 to 30 vessels waiting at the Soo (5). As vessel sizes increase, the operators believe that waiting times will increase. Currently most vessels going through the Soo have lengths in the range of 620 to 770 ft. As vessel size continues to increase, waiting times can be expected to increase because a greater percentage of the vessels will be able to use the Poe Lock only.

There is a waiting time problem at the Welland Canal. Some operators report that there may be delays of 5 days or more during periods of heavy traffic or if the weather has been bad (6). Operators report that the waiting times are particularly long near the end of the season when a large number of salties are coming into the system for one last trip (4). The salties do not handle well in the locks and channels of the Welland Canal and the St. Lawrence River and therefore take longer to lock through. In addition, the salties are generally relatively small vessels and go through the system at about 8 ft less than their desired draft. As a result, the ocean going ships are only carrying about 8,000 to 12,000 tons of cargo, which results in a lessened annual tonnage throughput.

### Capacity of Lock Systems

Fleet operators believe that the capacity of the current Welland Canal could be increased by about 40 to 45% by increasing the load of the average ship transit (8). Currently the average load per transit at the Welland Canal is about 12,000 tons, yet a maximum sized laker designed for the system can carry 26,000 tons per transit. These operators believe that the tolls for the Welland should be levied per lockage rather than per ton carried. They believe that the current system favors the smaller, less efficient carrier, since the actual cost of locking ships is about the same regardless of ship size.

### Problems with Winter Navigation

During extended season navigation fleet operators believe that the Coast Guard should use their icebreakers to keep the channels open and not just render assistance to vessels in distress (7). There are also improvements needed in system-wide ice management. Ice booms are needed in some places, and additional fixed aids to navigation are required to take the place of the navigation buoys that must be removed at the end of the traditional navigation season.

## 5.2 Comments of Ocean Fleet Operators

### Requirement for a Larger System

International shipping operators generally cite the draft restrictions as the principal problem with the size of the Seaway system (8). Most of these ships are less than 550 ft long, but they have to come into the Seaway at about 8 ft less than their optimal draft, which results in a substantial reduction of their carrying capacity.

### Queuing Problems

International operators all cite the problem of obtaining pilots as being the primary delay problem in the Welland Canal and St. Lawrence River (9, 10). These operators say that the wait for Canadian and American pilots creates delays and unnecessary expenses. Heavy loads of one-way traffic during rush seasons results in most of the pilots located at one end of the system, and there is a delay in returning them to service additional ships. International shippers also report lines of 15 to 20 ships at the Welland Canal during the peak operating periods (6).

## 5.3 Comments of Lock Operators

### Soo Locks

Locking system problems identified by the operators at the Soo Locks chiefly concern late season operations in ice (11).

There is a problem with the slight angle that occurs on the approach wall to the Poe Lock. Large vessels have trouble turning to avoid the angle of this wall when heading downbound. The problem becomes more severe in winter when ice accumulates on the wall, leaving less clearance.

The hydraulically operated gates of the Poe Lock are not designed to push the ice away. This presents some problems during winter operations.

The Poe Locks are 110 ft wide and are designed to lock vessels that are 100 ft wide but, in fact, lock vessels up to 105 ft wide. In heavy winter ice conditions, the clearance is, in the opinion of the operators, not adequate for the largest ships. Locking wide ships during heavy ice conditions is also expected to increase the need for lock wall maintenance.

### Welland Canal Locks

The Welland Canal has a capacity problem (12). Measures that could be taken to increase system capacity are discussed in detail elsewhere in this report. The problems with the system involve single locks, sections of the channel that are restricted to one-way traffic, and obtaining a more even flow of traffic approaching the system. Basically, these are not problems with the lock systems but rather alternatives that could be considered to increase the capacity of the system.

There is a problem in fueling ships at Port Colborne which creates traffic control problems and delays. A more efficient fueling facility would be expected to reduce these delays.

### St. Lawrence River Locks

The St. Lawrence River Locks are not capacity limited now and are not expected to approach capacity for many years (13). As a result, there are no special operational problems that affect the efficiency of the system. Some maintenance problems do occur, but these are being corrected with a regular annual maintenance program. Some alternatives to increase capacity have been considered. For example, a program to tow ships through the locks instead of having them go through on their own power has been considered. Installation of special flushing ports to speed up the filling and emptying of the locks has also been considered. At the present time, however, in the opinion of the lock operators, there are no operational problems that affect the locking capacity.

## 5.4 Section 5 References

1. American Steamship Company, Buffalo, New York.
2. Canada Steamship Lines, Montreal, Quebec.
3. Cleveland Cliffs Steamship Company, Cleveland, Ohio.
4. Upper Lakes Shipping, Ltd., Toronto, Ontario.
5. Columbia Transportation, Cleveland, Ohio.
6. Shipping Federation, Montreal, Quebec.
7. U.S. Steel Corporation, Great Lakes Fleet, Duluth, Minnesota.

8. Yugoslav Great Lakes Line, Chicago, Illinois (Agent).
9. Federal Commerce and Navigation, Montreal, Quebec.
10. Calley Motorships, Ltd., Montreal, Quebec.
11. Corps of Engineers, Sault Ste. Marie, Michigan, Interview  
January 1981.
12. The Seaway Transport Canada, Traffic Control, St. Catherines,  
Ontario.
13. St. Lawrence Seaway Development Corporation, Washington,  
D.C.

## 6. ALTERNATIVES FOR INCREASING LOCK CAPACITY

### 6.1 Potential Capacity Expansion Alternatives

The objective of this subtask is to identify and evaluate the possible capacity expansion measures which could be implemented at the three sets of locks in the Great Lakes/St. Lawrence Seaway System. Capacity expansion measures may be physical improvements to the system, whether major construction or minor modifications, or they may be changes in operating procedure. In either case, the ultimate goal is to meet the projected cargo demands without exceeding the capacities of the lock systems. Capacity of a lock system may be defined in general terms as the level of tonnage at which a small increase in tonnage will cause large, unreasonable delays for ships using the locks.

The proposed capacity expansion measures for the Great Lakes/St. Lawrence Seaway System can be divided into six categories by capacity expansion objectives. Each of these categories may encompass one or more methods of accomplishing the general capacity expansion objective. The capacity expansion measures, broken down by objective, are described below.

#### 6.1.1 Reduce Time Per Lockage

Reduction of the time a ship takes to pass through a lock would result in an increase in the number of lockages possible over the shipping season. This would result in an increase in the tonnage capacity of the lock. A lockage consists of a series of steps, all taking time to perform. Reduction of the time required for any of these steps would result in a reduction of lockage time. Times might be reduced by changes in the lock operating procedure, modification of the lock equipment, or structural improvements to the lock and surrounding channels.

##### 6.1.1.1 Assist Ship Into Lock

General Description: Physical assistance could be given to a ship to move it into the lock rather than solely relying on the ship's power. A ship under its own power must proceed into a lock very slowly to minimize the chance of damaging the lock or the ship. A ship with external assistance might be moved into the lock faster with the same degree of safety.

Capacity Increase: Lock cycle time would be reduced because the ship would be positioned in the lock faster. Ship exit time might also be reduced.

Methods of Implementation: Several types of assistance systems could be utilized at locks. These are:

Shunter tugs - tug boats to accelerate the movement of ships into and out of the locks

Mules - locomotives to tow ships into position in the lock

Traveling Keels - wheeled, movable mooring posts traveling on rails to pull ships through the lock

Winches - cable assembly with powered winches to pull ships through the lock.

General Effectiveness: The entry and exit time of each ship utilizing the lock would be decreased with this alternative. A direct benefit of additional lockages per season could be expected.

#### 6.1.1.2 Reduce Amount of Ship Maneuvering Required

General Description: Modifications to the lock approach alignment system would allow a ship to align itself for entry into the lock with less maneuvering. A ship could be readied for entry into the lock immediately after completion of the prior lockage.

Capacity Increase: The idle lock time, wasted while waiting for a ship to maneuver into position, would be eliminated or reduced.

Methods of Implementation: Several methods of aligning a ship with the lock could be used. Approach walls could be re-aligned to form a "chute" to enter the lock. Wind and wave deflectors could be installed to minimize drift. A ship alignment and mooring system with waiting areas as close to the locks as possible could be installed in the approach channels. An electronic guidance system could be installed to aid in alignment of the ship.

General Effectiveness: The effectiveness of this alternative will vary with the conditions at the lock. Under unfavorable conditions, such as bad weather or poor visibility, significant gains could be realized. Otherwise, significant benefits will only be realized at locks which have poor approach and waiting areas such as Welland #7 Lock and the Beauharnois Locks.

#### 6.1.1.3 Increase Ship Speed Entering Lock

General Description: A ship would be allowed to enter the lock under its own power at a faster speed. More extensive safety precautions, such as additional fenders and bumpers, must be taken to reduce the chance of lock damage. Resistance to the ship by the water which is displaced in the lock by the ship will increase with higher speed. This resistance would act as a safety barrier in addition to the fenders and bumpers.

Capacity Increase: The ship would enter the lock faster and with better response on the controls. Small reductions of lock cycle times would be gained.

Methods of Implementation: Safety measures to prevent the ship from damaging the lock would include replaceable fenders, energy absorbers, and rolling fenders.

General Effectiveness: Small gains in time would be realized from this alternative. These gains would decrease with increasing ship size, becoming minimal with the largest ships. Fenders and energy absorbers are partially in use at the St. Lawrence River and Soo Locks.

#### 6.1.1.4 Decrease Lock Chambering Time

General Description: The time taken to raise or lower a ship in a lock might be decreased by increasing the filling/dumping rate of the lock. This time might also be decreased by improving ship handling procedures.

Capacity Increase: Reducing the filling/dumping time of the lock would directly reduce the lock cycle time, increasing lock capacity. Improving ship handling procedures during lockage would minimize the chance for delay due to ship handling. Ship exit times might also be reduced.

Methods of Implementation: Lock filling/dumping times would be reduced by increasing culvert sizes, reducing valve operating times, or installing self-cleaning trash racks to prevent blockage of the water intakes. Ship handling times would be reduced by installing floating bollards which would reduce the demands on lock personnel to secure the ship. Longitudinal hydraulic assistance might be given to ships exiting downstream by using water from the upstream side of the lock to help accelerate the ships out of the lock.



General Effectiveness: Decrease of lock filling/dumping times would decrease the cycle time of each lockage regardless of ship size. A corresponding increase in capacity would be expected. The floating bollards and downstream hydraulic assistance would be especially effective in reducing handling problems of large ships. The effect on cycle times would yield a small increase in capacity.

#### 6.1.1.5 Remove Channel Restrictions

General Description: Channel restrictions such as bridges or one-way channels could delay ships approaching locks. The result could be idle time at a lock while waiting for a ship to negotiate the restricted passage. This idle time, which could have been used to lock a ship, would decrease the lock capacity.

Capacity Increase: Elimination of channel restrictions would ensure that no lock time will be wasted waiting for a ship to negotiate the approach channel. The limits to capacity would then be strictly the capacity of the lock. Elimination of channel restrictions could allow an increase in the speed limit in the restricted areas, decreasing the ship travel time.

Methods of Implementation: Channel restrictions could be eliminated by dredging or straightening narrow, winding channels, replacing bridges that have narrow spans with larger ones, etc.

General Effectiveness: Locations on the GL/SLS System which have restricted channels would benefit from these improvements. Lock capacities could be increased at the Welland and St. Lawrence River Locks where channel restrictions cause wasted time at the locks.

#### 6.1.1.6 Improve Lock Operation Procedures

General Description: Improvement of the operating procedures for the locks would ensure that each lock is operated efficiently and that no delays would be caused by operational errors.

Capacity Increase: The effect that this alternative would have on increasing lock capacity would be to prevent unexpected delays due to poor lock operation or ship handling. It would ensure that no unnecessary delays occur.

Methods of Implementation: In order to ensure the most efficient operation of the lock, the operating procedure should be prominently displayed in the control room. Trouble indicators and closed circuit television of the critical operations such as are used at the Welland Lock would be implemented. An automated control system would operate the lock equipment exactly according to the operating procedure. Additional personnel at the lock could increase the efficiency of ship handling, decreasing the chambering time.

General Effectiveness: Under ideal conditions these alternatives will provide little or no increase to lock capacity. However, if the lock is not operated by the designed procedure and inefficiencies exist, lock capacity could be increased. This was evident on the Welland Canal where remote indicators, televisions, and radio controls have increased lock capacity.

#### 6.1.2 Increase Ship Capacity

The tonnage capacity of the GL/SLS System might be increased to meet the projected cargo demand levels by increasing the capacity of the ships operating on the system. Ship capacity might be increased by increasing the ship's draft, size, or both. Currently lock, channel, and harbor dimensions are the restraining factors on ship dimensions. Increases in the allowable ship dimensions would require major lock modifications or replacements. Some channel and harbor dredging would also be required. An analysis of the work required was performed by the COE in the "Maximum Ship Size Study".

##### 6.1.2.1 Increased Allowable Ship Draft

General Description: With the existing high water levels, ships operating on the Upper Great Lakes are restricted to drafts of 27 ft while those operating through the St. Lawrence River and Welland Canal are limited to 26 ft. At low water datum ships are limited to 25.5 ft throughout. Many of these ships have the capability of operating to drafts of 36 ft. Increase of the allowable ship draft through the GL/SLS System would increase the system capacity.

Capacity Increase: A small increase in allowable vessel draft would significantly increase the tonnage hauled in each ship. The tonnage capacity of the locks would be increased without changing the total number of lockages.

Methods of Implementation: To allow an increase in ship draft, the allowable draft in each lock would have to be increased.

Harbors and channels which these deeper draft ships would use would have to be dredged.

General Effectiveness: The capacity of the GL/SLS System would be significantly increased through an increase in allowable ship draft. Ship cost per ton hauled would be decreased by an increase in ship draft.

#### 6.1.2.2 Increase Allowable Ship Size (Length/Width)

General Description: Capacity of the GL/SLS System would be increased by allowing larger ships to operate through the System. Ship size increases would be in length and beam dimensions.

Capacity Increase: An increase in allowable ship beam and length would cause a change in fleet mix to ships having larger capacities. A greater amount of tonnage would be passed per lockage in such ships.

Methods of Implementation: To allow larger ships through the entire GL/SLS System, all of the St. Lawrence River and Welland Canal Locks would have to be replaced. In addition, some modification would be required to the Soo Locks, depending upon the allowable maximum ship size. If larger ships are only required in the Upper Lakes, some modifications to the Soo Locks such as lengthening the MacArthur Lock or combining the Sabin and Davis into one lock might be sufficient. In all cases, harbor and channel dredging would be required.

General Effectiveness: Lock capacity would be increased by larger ships. The amount of tonnage passed with each lockage would increase with larger ships. The maximum ship size for this study would be such that capacity would not be reached until after 2050.

#### 6.1.2.3 Increase Allowable Ship Draft and Size

General Description: This alternative could be considered as an optimization of Increase Allowable Ship Draft and Increase Allowable Ship Size. The GL/SLS System would be optimized by trading increased capacity and decreased shipping cost benefits against system construction costs. The recommended system would be the one that meets the projected 2050 cargo demand with the highest benefit/cost ratio.

Capacity Increase: Since the projected 2050 cargo demand would be one of the design parameters for the optimized system, capacity would not be reached before that time.

Methods of Implementation: All of the GL/SLS System locks would have to be modified or replaced to pass the optimal maximum size ship. Channels and harbors would have to be dredged to meet ship draft, length, and beam.

General Effectiveness: An optimization of the GL/SLS System to a maximum sized ship that will meet the projected cargo demand would be the most effective alternative; however, possibly also the most costly.

#### 6.1.3 Increase Tonnage Per Lockage

System capacity could be increased by increasing the amount of cargo passed through on each lockage. This reasoning was implied in the previous section; however, in that case, major lock renovations would be required. In this section, no structural modifications to the locks would be required. Capacity would be increased by changes in operating policy.

##### 6.1.3.1 Favor Larger Ships

General Description: Lockage of a smaller ship which does not completely fill the lock wastes "lockage space" which a larger ship could utilize to transport additional cargo. The largest ship which would fit in a lock would optimize the cargo transporting capacity of the lock.

Capacity Increase: Lock capacity would be increased by giving preference to larger ships because the tonnage transported in each lockage would be increased.

Methods of Implementation: Lock operating procedures could be modified to favor the use of ships which more completely fill a lock. This would cause a change in fleet mix and new ship construction towards larger ships. Two methods of influencing this change would be to give larger ships priority at the locks or to change Seaway tolls so that larger ships would be charged at a lower rate per ton of cargo than smaller ships.

General Effectiveness: These measures of favoring a larger ship will give an additional incentive to utilizing the largest possible ships. Other factors may be involved such as limitations in certain harbors which may lower this effect.

#### 6.1.3.2 Favor Cargo Carrying Ships

General Description: Ships which do not carry cargo occupy useful space in a lock or may require separate lockages which could otherwise be used to transport cargo. Primarily these are pleasure craft; however, large percentages of cargo ships in ballast also limit capacity. A preference of cargo carrying ships over non-cargo carrying ships could be implemented to increase lock capacity. Cargo carriers in ballast would be encouraged to take loaded backhauls.

Capacity Increase: Lockages which do not transport cargo would be minimized and those extra lockages would be utilized by cargo carrying ships.

Methods of Implementation: The effects of pleasure craft on lock capacity could be minimized by providing separate facilities to transit the pleasure craft, locking pleasure craft only at set times of the day, or by giving pleasure craft low priority while there are cargo ships waiting. Ships in ballast might also be given low priority when loaded ships are waiting.

General Effectiveness: Pleasure craft take more time to load into a lock and can waste lockages which could be used to transport cargo. Reduction in these lockages would increase the cargo transport capacity of the locks. This alternative does not apply to the Soo Locks where separate facilities already exist.

#### 6.1.3.3 Feeder/Transshipment

General Description: Oceangoing ships which operate through the GL/SLS generally do not carry as much cargo as the lake ships. This is due to the design of the ships and the fact that the oceangoing ship cannot use much of its potential draft. More tonnage is transported per lockage on the average with lake ships. Ocean ships are also generally slower and harder to maneuver, especially in the Welland Canal and St. Lawrence River, taking more time to lock through. Exceptions are the limited number of oceangoing vessels specifically designed for GL/SLS service.

Capacity Increase: Reducing the number of oceangoing ships in the GL/SLS fleet and replacing them with lake ships would increase lock capacity by increasing the amount of cargo transported per lockage and by increasing the possible number of lockages. A general cargo lake ship feeder trade would develop to transport the general cargo which is currently carried by ocean ships.

Methods of Implementation: Oceangoing ships would be discouraged from entering the GL/SLS System by changing the tolls to favor lake ships. The tolls would make it more economical for the ocean ships to put in at Quebec City or Montreal where they can use their deep draft design. Cargo would be transshipped to and from these points by lake ships designed to operate efficiently through the locks.

General Effectiveness: Complete elimination of ocean-going ships could greatly increase the capacities of the Welland Canal and St. Lawrence River Locks. The number of lockages per season and the volume transported per lockage would both increase.

#### 6.1.3.4 N-Up/N-Down Policy

General Description: The locks currently operate on a first come-first serve basis. Implementation of a 1-up/1-down policy would use the effort required to turnback a lock in order to take a second ship in the same direction, to transport a ship going in the opposite direction. However, if the sum of the times for a turnback exit, a turnback, and a turnback entry is less than that for an exchange exit and entry, an N-up/N-down rule where N is greater than one could save time.

Capacity Increase: The 1-up/1-down rule would eliminate empty lockages required to turnback a lock. Each lockage would contain a ship. The N-up/N-down rule, if applicable, would reduce ship alignment and entry time into the lock.

Method of Implementation: No structural changes to the lock systems would be required. Only a change in operating procedure need be implemented.

General Effectiveness: It appears that, in general, the 1-up/1-down policy would increase capacity over a first come-first serve operation when queues exist in both sides of the lock. The direct benefit would be that a vessel would be transported in every lockage. No lockages would be wasted.

#### 6.1.4 Season Extension

The GL/SLS System is not utilized year-round. More ships are required to transport cargo over a reduced season than would be required to transport the same amount of cargo over a full year season. Also, more lockages might take place over an extended season than over the limited season, even though winter lockages take more time.

General Description: Different lengths of season extension could be implemented, along with combinations of extensions in the Upper Lakes and in Welland Canal and St. Lawrence River. The demands for intra-lake and for overseas cargo would dictate the optimal season length.

Capacity Increase: System capacity would be increased because the cargo demand would be spread out over a longer period of time. This would require the use of less ships at a given time, while at the same time increasing the number of ships that could travel through each lock during a season.

Method of Implementation: Ice control facilities would be required at each lock to ensure lock operation during the winter. Icebreakers would be required to clear harbors and channels and to assist ships when required.

General Effectiveness: Season extension has been given much consideration over the past decade. It is considered to be a viable capacity expansion measure, while at the same time providing other benefits such as reducing the required stockpiling of materials required for manufacturers who receive their raw materials via the Lakes.

#### 6.1.5 Construct Replicate Locks

One of the problems with the St. Lawrence River Locks and five of the Welland Canal Locks is that there is no overall system redundancy. Any major breakdown causing any one of those locks to shut down would shut down the entire system. This is also partially true at the Soo Locks, where shutdown of the Poe Lock would immobilize all vessels limited to the Poe by size.

General Description: A total redundancy system consisting of new locks operating in parallel to the existing locks would be constructed. These locks could be the same size as the existing locks, therefore requiring no modifications to harbors or connecting channels.

Capacity Increase: Under normal conditions, the effect of these replicate locks would be roughly to double the system capacity. It would be possible that two ships could be locked at the same time. During periods when a lock must be shut down for repair, ships would still be able to travel by means of the other lock.

Methods of Implementation: Constructing parallel locks would be a major construction project, at least equal to that of building the original locks.

General Effectiveness: Replicate locks would have the effect of almost doubling the system capacity. It would alleviate the problem of system blockage while a lock is out of service. It would allow for locks to be brought off-line for scheduled preventive maintenance, prolonging the life of the locks and reducing costly emergency maintenance.

#### 6.1.6 Other Alternatives

The following expansion alternatives could be considered to be radical changes to GL/SLS System operations. These are not proven alternatives and technology may not as yet have been developed which could allow these alternatives to be implemented in a cost effective manner. They must, however, be considered in long range system planning.

##### 6.1.6.1 Traffic Control System

General Description: In its most complex form, this alternative would be analogous to air traffic control systems. The control system would plan GL/SLS System operation to control the arrival of each ship at the locks. However, the most practical form would be three individual systems at each of the three lock sets.

Capacity Increase: The proposed control system would even out the traffic flow through the locks. Ship arrivals at locks would be scheduled in order to minimize waiting times due to random arrivals and ship approach times would be decreased.

Methods of Implementation: Each lock system would be controlled by a computer control center. The computer would know the locations, capacities, etc. of all ships near the locks, weather conditions, and other system parameters. The computer would optimize lock use, determining ship speeds, lock arrival times, and locking priorities. Ships would be relayed this information by radio controllers with duties similar to air traffic controllers.

General Effectiveness: Some capacity increase would be gained through a reduction of waiting times and approach times at the locks. In addition, congestion at bottleneck passages would be reduced and safety would be increased.



## 6.2 Preliminary Screening of Capacity Alternatives

Table 7 summarizes the capacity expansion measures which were described in the preceding section. The operation parameter(s) of the Lock Capacity Model that would be affected by each expansion alternative are given. Qualitative estimates of the effects of each alternative on increasing capacity, and of the cost of the alternative are listed. Lastly, the decision of whether or not to further pursue the alternative in this study is made. Reasons for alternative elimination in this preliminary screening are given.

## 6.3 Estimated Capacity Improvements

The following paragraphs give the estimated changes in the operating parameters affected by each of the proposed capacity expansion alternatives. Since available data for capacity expansion is scarce, ranges have been estimated for each alternative. These ranges represent a quantitative, best engineering judgement on the effect of each alternative.

Table 8 summarizes the capacity increase information given in the following paragraphs. This information is tabulated in a form that may be incorporated into the system capacity model being prepared for use in the study of system capacity. This will allow determination of the system improvements required to meet the projected cargo demand through the year 2050.

### 6.3.1 Reduce Time Per Lockage

#### 6.3.1.1 Assist Ship Into Lock

Shunter Tugs and Mules: SLSA estimates capacity increases up to 10% at the Welland Canal. It is assumed that similar increases could be realized at the St. Lawrence River and Soo Locks. The estimated decrease in locking time is therefore estimated to be 5 to 10% at the Soo, 5 to 10% at the Welland, and 5 to 10% at the St. Lawrence River Locks.

Traveling Kevels and Winches: Ship speed entering the lock would increase; however, time for hook-up would negate some of the gains. The estimated gain in entry speed is 0.5 to 1.5 mph. The estimated decrease in locking time for all locks is 5 to 10%.

TABLE 7 PRELIMINARY SCREENING OF CAPACITY EXPANSION ALTERNATIVES

EXPANSION ALTERNATIVE	OPERATIONAL PARAMETER	CAPACITY INCREASE	IMPLEMENTATION COST	FURTHER INVESTIGATION
6.1.1 <u>Reduce Time Per Lockage</u>				
Assist Ship Into Lock				
Shunter Tugs	Locking Time	Medium	High	Yes
Mules	Locking Time	Medium	High	Yes
Traveling Kevels	Locking Time	Medium	Medium	Yes
Winches	Locking Time	Medium	Medium	Yes
Reduce Maneuvering				
Re-align Approach Walls	Locking Time	Small	High	Yes
Wind & Wave Deflectors	Locking Time; Avail. Operating Time	Small	Low	Yes
Ship Alignment and Mooring System	Locking Time	Small	High	Yes
Elect. Guidance	Locking Time	Small	High	No, only in conjunction with winter navigation.
Increase Ship Speed	Locking Time	Small	Low	Yes
Decrease Chambering Time				
Reduce Dump/Fill Time	Locking Time	Small	High	Yes
Self-Cleaning Trash Racks	Locking Time	Small	Low	No, impact on capacity is assumed negligible.
Floating Bollards	Locking Time	Small	High	No, only in conjunction with lock replacement.
Downstream Longitudinal Assistance	Locking Time	Small	Low	Yes
Remove Channel Restrictions	Avail. Operating Time	Small	High	Yes
Improve Operating Procedures	Locking time	Small	Low	Yes

TABLE 7 PRELIMINARY SCREENING OF CAPACITY EXPANSION ALTERNATIVES (CONTINUED)

EXPANSION ALTERNATIVE	OPERATIONAL PARAMETER	CAPACITY INCREASE	IMPLEMENTATION COST	FURTHER INVESTIGATION
6.1.2 <u>Increase Ship Capacity</u>	Fleet Mix; Locking Time	Large	High	Yes
6.1.3 <u>Increase Tonnage Per Lockage</u>				
<u>Favor Larger Ships</u>	Fleet Mix	Large	Low	Yes
<u>Favor Cargo Carrying Ships</u>	Non-commercial Locking Requirements	Large	Low-High	Yes
<u>Eliminate Pleasure Craft</u>	Fleet Mix	Medium	Low	Yes
<u>Minimize Empty Backhauls</u>	Fleet Mix	Large	Medium	Yes
<u>Feeder/Transshipment</u>	Locking Time	Small	Low	No, 1-up/1-down already in use if queues. N>1 not effective.
<u>N-Up/N-Down</u>				
6.1.4 <u>Season Extension</u>	Length of Season; Winter Operating Proc.	Large	High	Yes
6.1.5 <u>Replicate Locks</u>	Available Operating Time	Large	High	Yes
6.1.6 <u>Other Traffic Control System</u>	Locking Time	Low	Low	yes

TABLE 8 ESTIMATED CAPACITY IMPROVEMENTS

EXPANSION ALTERNATIVE	OPERATIONAL PARAMETER	PARAMETER CHANGE		
		S00	WELLAND	SLR
6.3.1 <u>Reduce Time Per Lockage</u>				
Assist Ship into Lock	Locking Time	- 5-10%	- 5-10%	- 5-10%
Shunters & Mules	Locking Time	- 5-10%	- 5-10%	- 5-10%
Traveling Kevels and Winches	Locking Time	- 0-1%	- 0-4%	- 0-2%
Reduce Maneuvering	Locking Time	- 0-2%	- 0-2%	- 0-2%
Approach Walls	Avail. Operating Time	+ 0-2%	+ 0-2%	+ 0-2%
Wind & Wave Deflectors	Locking Time	- 0-5%	- 0-10%	- 0-5%
Increase Ship Speed	Locking Time	- 0-2%	- 0-5%	- 0-2%
Decrease Chambering Time	Locking Time Downstream	- 1-10%	- 0-5%	- 1-10%
Reduce Dump/Fill Time	Avail. Operating Time	+ 1-3%	+ 2-6%	+ 1-5%
Downstream Longitudinal Assist.	Locking Time	- 1-2%	- 1-2%	- 1-2%
Improve Channel	Locking Time; Fleet Mix			
Improve Operating Procedures				
6.3.2 <u>Increase Maximum Ship Size</u>				
		See Figure 12	Max. Vessel Size	Max. Vessel Size

TABLE 8 ESTIMATED CAPACITY IMPROVEMENTS (CONTINUED)

EXPANSION ALTERNATIVE	OPERATIONAL PARAMETER	PARAMETER CHANGE		
		S00	WELLAND	SLR
6.3.3 <u>Increase Tonnage Per Lockage</u> Favor Larger Ship	Fleet Mix	% of max. size ships	% of max. size ships	% of max. size ships
Favor Cargo Carrying Ships: Eliminate Pleasure Craft	Non-commercial Locking Requirements	0	+1-2 lockages/day	+1-2 lockages/day
Minimize Empty Backhauls	Fleet Mix	No. of Ships	No. of Ships	No. of Ships
Feeder/Transshipment	Fleet Mix	Capacity of Ship	Capacity of Ship	Capacity of Ship
6.3.4 <u>Season Extension</u>	Season Length; Locking Time; Fleet Mix	9.0-12 mos. + 0-10 min.	9.0-12 mos. + 0-10 min.	9.0-12 mos. + 0-10 min.
6.3.5 <u>Replicate Locks</u>	Avail. Operating Time	+ 65-100%	+ 100-125%	+ 100-125%
6.3.6 <u>Other</u> Traffic Control System	Locking Time	- 1-8%	- 1-5%	- 1-8%

#### 6.3.1.2 Reduce Amount of Ship Maneuvering Required

Re-Align Approach Walls and Ship Alignment System: The time for ship positioning to gain entry to the lock will be decreased at locks which do not have adequate approach walls. Only small improvements could be made at the St. Lawrence River Locks. The Soo Locks do not require approach wall modification; however, the alignment system could decrease lock time. The estimated decrease in locking time is 0 to 4% at the Welland Canal, 0 to 1% at the Soo, and 0 to 2% at the St. Lawrence River.

Wind and Wave Deflectors: Small reductions in lock entry time will be realized. Total lock operating time will be increased because locks will not be shut down due to wind conditions. The estimated decrease in locking time for all locks is 0 to 2%. The estimated increase in available operating time for all locks is 0 to 2%.

#### 6.3.1.3 Increase Ship Speed Entering Lock

Lock entry time would be decreased due to a small increase in entry speed with the proposed improvements, improving lock safety. A partial safety system is currently in place at the Soo and at the St. Lawrence River Locks. The estimated decrease in locking time is 0 to 5% at the Soo and St. Lawrence River and 0 to 10% at the Welland.

#### 6.3.1.4 Decrease Lock Chambering Time

Reduce Dump/Fill Times: Dump/fill times could be reduced 1 to 2 minutes on each lock, with larger gains realized at the Welland Canal Locks. The estimated decrease in locking time for the Soo and St. Lawrence River is 0 to 2% and at the Welland Canal, decreases of 0 to 5% could be obtained.

Downstream Longitudinal Assistance: A small reduction in exit times due to an increase of approximately 1 mph in exit speed would be realized on downstream bound ships. The estimated decrease in locking time for the Welland Canal Locks is 0 to 5% and for the Soo and St. Lawrence River Locks is 1 to 10%.

#### 6.3.1.5 Remove Channel Restrictions

The Welland Canal would benefit most from reducing channel restrictions. Smaller improvements could be realized at the St. Lawrence River and even smaller improvements at the Soo.

The estimated increase in available operating time is 1 to 3% for the Soo, 2 to 6% for the Welland, and 1 to 5% for the St. Lawrence River.

#### 6.3.1.6 Improve Operating Procedure

Minor gains would be realized at all locks due to more efficient operation. The estimated decrease in locking time for all locks is 1 to 2%.

#### 6.3.2 Increase Ship Capacity

The tonnage of cargo transported per lockage would increase with larger and deeper draft ships; however, locking times will also increase. The net gain in system capacity must be determined using both the larger ship capacities and higher locking times.

Larger allowable ship sizes will change the fleet mix used by the capacity model to meet cargo projections. Figure 12 illustrated the increases in locking time that could be expected for larger ships based on cargo deadweight. This graph was obtained using available locking time data for the Soo Locks. The curve was fit using a linear regression technique. Larger ship sizes were extrapolated from this curve.

A theoretical system capacity for a given ship size can be determined by dividing the ship cargo capacity by locking time, and converting to a season basis. Actual system capacity will be less because not all ships will be of maximum size or will be fully loaded, and operating deficiencies do exist in the system.

#### 6.3.3 Increase Tonnage Per Lockage

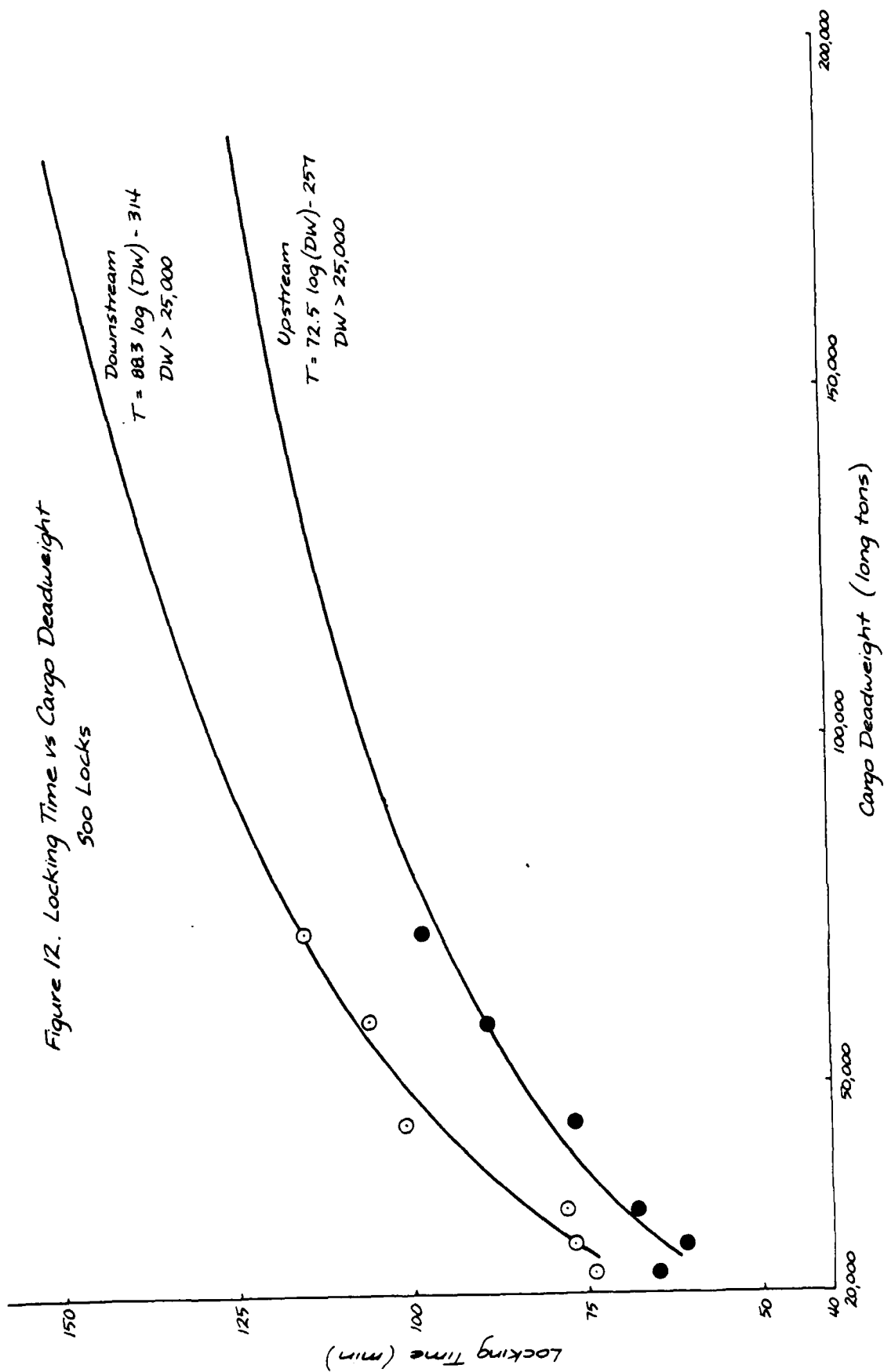
##### 6.3.3.1 Favor Larger Ships

Capacity increase will be accomplished by changes in the fleet mix to more ships of maximum size. The effect on capacity will be determined by exercising the capacity model. The maximum tonnage per ship for each lock is approximately 59,000 tons at the Soo and 26,000 tons at the Welland Canal and St. Lawrence River.

##### 6.3.3.2 Favor Cargo Carrying Ships

Eliminate Pleasure Craft: Spread over a season, pleasure craft probably cost shipping approximately 1 to 2 lockages per day at the St. Lawrence River and Welland Canal Locks.

Figure 12. Locking Time vs Cargo Deadweight  
500 Locks





Non-commercial traffic normally does not interfere at the Soo Locks where a separate facility is provided.

Minimize Empty Backhauls: Empty backhauls are a function of the cargo projections as they are distributed between upbound and downbound flows. If there is not enough cargo moving along the backhaul route, ships will come back in ballast. Fleet mix will be determined by the capacity model so as to fully utilize as much backhaul capacity as possible.

6.3.3.3 Feeder/Transshipment: Fleet mix will be altered to reduce the number of ocean ships moving through the lakes. The average tonnage hauled through the Welland Canal in 1979 was 12,000 tons, while for Lake ships alone it was 15,400 tons. The maximum Lake ship capacity is 26,000 tons through these locks.

#### 6.3.4 Season Extension

The length of the operating season and winter vessel and lock operating procedures will be changed. Operating season may be extended up to full-year operation. Locking times will increase during extended season operations and there will be delays as ice may have to be locked through before a ship may enter the lock. Estimated season lengths for all locks are 8.5 to 12 months. The additional locking time for all locks is estimated to be 0 to 10 min.

#### 6.3.5 Replicate Locks

By constructing replicate locks, the available operating time for lockages in the St. Lawrence River where no redundancy exists, and the Welland Canal where only partial redundancy exists, will be doubled. Installation of another lock, the size of the Poe, at the Soo Locks will double the capacity for handling 1,000 ft ships. The estimated increase in available operating time is 65 to 100% at the Soo, and 100 to 125% at the Welland Canal and St. Lawrence River.

#### 6.3.6 Other

Traffic Control System: Available operating time will increase because weather delays and traffic shutdowns would be reduced. Locking times will be reduced due to reduced approach times. The estimated decrease in locking time is 1 to 8% at the Soo and St. Lawrence River, and 1 to 5% at the Welland Canal.

#### 6.4 Estimated Cost of Capacity Improvement

Table 9 gives the estimated cost of each of the proposed capacity expansion measures. Detailed cost information is not available for most of the proposed alternatives. The costs given in this study are rough, order-of-magnitude comparative figures only. However, considering the uncertainties involved in projecting cargo demand and system use criteria through the year 2050, this cost data is judged adequate for this analysis. All expansion alternative costs given in Table 9 are expressed in 1981 dollars.

The estimated capacity improvement costs are the capital costs required to implement each of the proposed capital improvements. They do not include operation and maintenance costs, nor do they include costs to system users such as increased tolls. No contingency or engineering overhead costs have been added.

#### 6.5 Summary of Capacity Expansion Measures

The potential structural and non-structural capacity expansion alternatives which were developed in this task will be input into the GL/SLS System capacity model in Task 8. The model inputs will consist of the six general capacity expansion objective categories discussed previously. Several options exist for each capacity expansion objective, comprised of one or more specific capacity improvement measures. These options will be tested in the model to develop approximately twenty capacity improvement scenarios that will increase the GL/SLS System capacity to meet the projected cargo demands through the year 2050.

Each of the general capacity expansion objectives has been described in detail, along with the specific means of achieving these objectives. To summarize from these preceding sections, the general capacity expansion objectives to be used to develop the improvement scenarios are as follows:

- Reduce Time Per Lockage: Operational and minor structural improvements would be made to increase the number of lockages possible per season.
- Increase Ship Capacity: Major structural improvements to locks, harbors, and channels would be made to allow the use of larger ships thereby increasing overall system capacity.

TABLE 9 ESTIMATED CAPITAL COST OF CAPACITY IMPROVEMENT  
(Million \$; 1981 Costs)

EXPANSION ALTERNATIVE	SOO	WELLAND	SLR
<u>6.1.1 Reduce Time Per Lockage</u>			
Assist Ship Into Lock			
Shunters or Mules	125	200	175
Traveling Kevels	12	17	15
Winches	3	5	4
Reduce Maneuvering			
Approach Walls	19	34	29
Wind & Wave Deflectors	2	4	4
Increase Ship Speed	2	4	3
Decrease Chambering Time			
Reduce Dump/Fill Time	36	90	74
Downstream Longitudinal Assistance	5	8	7
Improve Channel	55	110	250
Improve Operating Procedures	1	1	1
<u>6.1.2 Increase Maximum Ship Size</u>	Use the results of the "Maximum Ship Size Study" update in Task 5		
<u>6.1.3 Increase Tons Per Lockage</u>			
Favor Larger Ship	0	0	0
Favor Cargo Carrying Ship			
Alternate Pleasure Craft Lockages	-	0-80	0-80
Reduce Empty Backhauls	0	0	0
Feeder/Transshipment	0	0	0
<u>6.1.4 Season Extension</u>			
Proposal 1:	Superior, Huron & Michigan - year round; St. Clair and Erie - 10 mo; Welland, Ontario & SLR - 8.5 mo. Investment Cost = 240.		
Proposal 2:	Superior, Huron & Michigan - year round; St. Clair and Erie - 10 mo; Welland, Ontario & SLR - 9 mo. Investment Cost = 271.		
Proposal 3:	Superior, Huron, Michigan, St. Clair & Erie - year round; Welland, Ontario & SLR - 9 mo; Investment Cost = 425.		
Proposal 4:	Superior, Huron, Michigan, St. Clair & Erie - year round; Welland, Ontario & SLR - 9.5 mo. Investment Cost = 431.		

TABLE 9 ESTIMATED CAPITAL COST OF CAPACITY IMPROVEMENT (CONTINUED)  
(Million \$; 1981 Costs)

EXPANSION ALTERNATIVE	S00	WELLAND	SLR
Proposal 5: Superior, Huron, Michigan, St. Clair & Erie - year round; Welland, Ontario & SLR - 10 mo. Investment Cost = 451.			
Proposal 6: Superior, Huron, Michigan, St. Clair & Erie - year round; Welland, Ontario & SLR - 11 mo. Investment Cost = 501.			
6.1.5 <u>Replicate Locks</u>	96	473	520
6.1.6 <u>Other</u>			
Traffic Control System	1	1	2

- Increase Tonnage Per Lockage: The operational procedures of the locks or the system tolls would be changed to encourage maximum use of the cargo transporting capability of each lockage.
- Season Extension: Structural and operational modifications would be made to allow a longer shipping season.
- Construct Replicate Locks: Major structural improvements would be made to increase the effective lock availability time and thereby increase the number of lockages possible per season.
- Other Alternatives: There are potential capacity improvement alternatives which have not been fully developed but which must be considered in long range planning. These alternatives can be either structural or non-structural improvements.

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